ANNUAL REPORT

Revision 1

Carlsbad Environmental Monitoring & Research Center
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Carlsbad, NM 88220

2016

Executive Summary

The Carlsbad Environmental Monitoring and Research Center (CEMRC) has measured the levels of radiological and non-radiological constituents in samples of the WIPP exhaust air, ambient air, soil and drinking water collected at and in the vicinity of the U.S. DOE's Waste Isolation Pilot Plant (WIPP) during calendar year 2016. WIPP is a U.S. Department of Energy (DOE) mined deep geologic repository that has been in operation since March, 1999. From the first receipt of waste in March 1999 through the end of 2016, 91,000 cubic meters (m^3) of TRU waste have been disposed of at the WIPP facility. Over its lifetime, WIPP is expected to dispose of approximately 175,000 cubic meters of TRU waste from various DOE sites. The repository is now at about half of its planned capacity and is scheduled to be sealed in 2040. The primary radionuclides within the disposed waste are long-lived isotopes of plutonium (mainly ^{239}Pu, with a half-life of 24,100 years, and ^{240}Pu, with a half-life of 6,560 years) and shorter-lived isotopes of americium and curium, which account for more than 99% of the total TRU radioactivity disposed and/or scheduled for disposal within the repository. After almost fifteen years of successful and safe operations, the WIPP facility was suddenly shutdown in February 2014, due to a underground fire event and an unrelated accidental underground radiation release event. Since the facility was still undergoing a recovery process from the 2014 underground fire and radiation release events, there were no TRU waste disposal activities conducted at the WIPP facility in 2016. It is important to note that facility has been reopened after recovering from these two accidents in January, 2017 and has resumed limited waste disposal operations.

Following the February 2014 underground fire and radiation release events at the WIPP, the CEMRC has continued its efforts to conduct accelerated analyses of the WIPP underground air samples collected from Stations A and B throughout 2016. Rapid analyses were also performed on ambient air samples and on other environmental samples collected from within the vicinity of the WIPP site. The data collected were compared to similar data collected during the monitoring phase of the WIPP prior to the events to assess the radiological and ecological impacts, if any, of radiation on workers and on the general public living and working near the WIPP. Based on the analyses conducted by the CEMRC scientific staff, measured releases have been determined to be low and localized, and no negative radiation-related health effects among local workers or the public are expected.

This report summarizes the environmental samples collected and analyzed by the CEMRC during the calendar year 2016 to inform the public that there were no significant adverse impacts on the environment from WIPP facility operations in 2016, as determined from extensive environmental monitoring for both radiological and non-radiological constituents. In summary, the data from this environmental monitoring program shows that the environment around WIPP continues to be safe and that there are no reasons to suspect that there will be any negative environmental impact from the February 2014 underground fire or radiation release events.

CHAPTER 1 | INTRODUCTION

This section describes an overview of the WIPP site and the CEMRC's major environmental programs. The Waste Isolation Pilot Plant (WIPP) is a radioactive waste repository owned by the U.S. Department of Energy (DOE) for the permanent disposal of defense-related transuranic (TRU) wastes. Located in the Chihuahuan desert of southeastern New Mexico near Carlsbad, the facility is designed to permanently dispose of TRU wastes that were generated from research and the production of nuclear weapons at various DOE sites throughout the nation.

Environmental monitoring is a key component in the development and operation of any nuclear facility. Well after the facility had been sited and constructed, but before repository operations began, the DOE and local community leaders recognized the value of having an independent environmental monitoring program. With the help of the DOE, the New Mexico State University (NMSU) created the CEMRC, which is funded annually by the DOE through a financial assistance grant process that respects its independence in carrying out and reporting the results of its environmental monitoring program at and near the WIPP site. The CEMRC program maintains capabilities necessary for the rapid detection of radionuclides in the event of accidental releases from the repository or from the site during waste handling and/or disposal operations.

CHAPTER 2 | WIPP UNDERGROUND AIR MONITORING

This section summarizes the WIPP's underground air monitoring results for the calendar year 2016. The WIPP facility operates three effluent air monitoring stations known as Stations A, B, and C respectively. Each station is equipped with at least one fixed air sampler collecting particulates from the effluent air stream on a Versapor 47 mm filter. Station A samples the unfiltered underground exhaust air whereas Station B samples the underground exhaust air after HEPA filtration and, sometimes, non-filtered air during maintenance activities. Station C is used to sample the exhaust from the Waste Handling Building (WHB) where air exhausted from the WHB passes through double HEPA filters before being vented to the environment. The actual waste container serves as the primary confinement barrier in the WHB; while negative building pressure and HEPA filtration provide secondary confinement to potential radiological contamination. The effluent studies at Station A and Station B are a major component of the CEMRC WIPP Environmental Monitoring (WIPP-EM) program as they provide a measure of the level of

radioactivity present in the air within the repository (Station A) as well as the level of radioactivity present in the air that is released to the environment (Station B). In addition, if radioactive materials were to be released from the facility, one would expect to detect it at Station A and/or Station B before it is observed in the local population or environment. During the calendar year 2016, the actinides and gamma analyses were performed on the weekly composite filters collected from Station A and the monthly composite filters collected from the Station B.

The weekly monitoring of the air filter samples collected from Station A during 2016 showed frequent detections of ^{241}Am and $^{239+240}$Pu due to residual contamination in the underground from the 2014 radiation release event as well as ongoing cleanup efforts within the WIPP underground. Results from Station B showed only occasional detection of these two radionuclides during 2016. The ^{238}Pu level has been below the detection limit for Stations B throughout all of 2016. It is important to note that while still detectable by the CEMRC sophisticated instrumentation, the levels detected in Station B filters are deemed to be very low and are not expected to cause any adverse health to humans nor to the environment.

CHAPTER 3 | AMBIENT AIR MONITORING

This section summarizes the ambient air monitoring results for the calendar year 2016 in the vicinity of the WIPP site. A network of continuously operating ambient air samplers at three locations across the WIPP site were used to determine whether the nuclear waste handling and storage operations at the WIPP have released radionuclides into the environment. In addition, three new sets of high-volume air samplers were installed following the 2014 underground radiation release event and are located at: (1) Carlsbad (behind the CEMRC facility), (2) south side of Loving and (3) east side of the WIPP facility near the WIPP meteorological station. With respect to these new ambient air sampling stations, aerosol samples are currently only collected from two sites (Loving and Carlsbad) as the third high-volume sampling station located on the east side of the WIPP was not completely deployed until the summer of 2017. As a result, ambient air samples were collected from 5 separate locations in 2016, representing a total of 94 air particulate filter samples being collected and analyzed during 2016. These filters were collected over a period of 2 to 4 weeks depending on the levels of particulate matter that accumulated on the filters. Except for a few positive detections of Am and Pu in the nearby ambient air samples due to the ongoing cleanup activities occurring within the WIPP facility, there were no increases in radiological contaminants observed during 2016 that could have been attributed to the recent underground radiation release from the WIPP in the wider region. Additionally, the CEMRC has been monitoring radionuclide concentrations in the ambient air around the WIPP facility since the inception of the WIPP-EM program in 1996. With few exceptions, fallout from

atmospheric testing of nuclear weapons has been determined to be the primary source of Pu detected in ambient air prior to the 2014 underground radiation release event. One of the most interesting and important findings from the prior WIPP-EM aerosol studies was that $^{239+240}$Pu in aerosols from all stations exhibited seasonal patterns and that the peak $^{239+240}$Pu activities generally occur in the March to June timeframe, which is when strong and gusty winds in the area frequently give rise to blowing dust.

CHAPTER 4 | SOIL MONITORING

This section summarizes soil monitoring efforts conducted around the WIPP Site during the calendar year 2016. To better understand the long-term behavior of radionuclides in the WIPP environment, 18 soil samples were collected from Near Field sampling locations and analyzed in 2016. The soil sampling at Cactus Flats was not conducted in the calendar year 2016. Samples were analyzed for radionuclides expected to occur in the areas sampled. Our monitoring data indicate that concentrations of these radionuclides are comparable to the historical data recorded for these areas prior to arrival of TRU wastes in the WIPP and that there is no persistent contamination and no lasting increase in radiological contaminants near WIPP that can be attributed to the 2014 underground radiation release event specifically or to WIPP related activities in general.

CHAPTER 5 | DRINKING WATER

This section summarizes public drinking water monitoring results for the calendar year 2016. Public drinking water samples are routinely sampled from six drinking water sources in the region of the WIPP including the City of Carlsbad Sheep Draw and Double Eagle water systems, as well as the Hobbs, Loving, Malaga, and Otis municipal water systems. While it is unlikely that these sampling locations would be affected by any WIPP-related radioactivity releases, the samples are collected and analyzed regularly because water is a primary vector in the food chain and therefore, is important to area constituents. Therefore, the CEMRC's drinking water monitoring program fulfills the following environmental challenges: protecting human and environmental health, assuring local residents about the quality of their drinking water, and assessing the long-term trends and environmental impacts of the WIPP on local water supply systems. The absence of TRU radionuclides in drinking water samples demonstrates that there has been no adverse impact to the population or to the environment from WIPP-related activities.

CHAPTER 6 | LOW BACKGROUND RADIATION EXPERIMENTS

This section summarizes the research activities occurring in the WIPP underground related to the Low Background Radiation Experiments (LBRE) conducted by scientists from the New Mexico State University Biology Department. The LBRE scientists utilize an underground laboratory that is located 2,150 feet underground in the northern research area of the WIPP repository. Conducting experiments this far beneath the earth's surface provides a shield that protects experiments from many forms of natural and cosmic radiation providing a near radiation-free environment in which the scientists expose various media (microbes, nematodes, and plants) to varying levels of radiation to see how the presence and/or absence of radiation affects the growth, survival, and stress resistance of their research media. Results obtained thus far show that the absence of radiation is often more harmful or stressful on the research media as compared to natural levels of radiation.

CHAPTER 7 | WHOLE BODY COUNTING

In addition to the monitoring of environmental media (air, soil, and drinking water), the CEMRC also operates a Lung and Whole Body Counting (LWBC) lab that performs *in vivo* measurements of the internally deposited radionuclides in humans and has been performing such measurements since 1997 for public volunteers living within a 100-mile radius of the WIPP facility as well as for WIPP radiation workers and other nuclear-related entities in the surrounding area. Prior to the WIPP becoming operational, the CEMRC LWBC lab performed *in vivo* measurements, also referred to as counts, on 366 public volunteers in order to establish a baseline of radiological activities in the inhabitants within the local population. The WIPP became operational in March 1999, accepting its first waste shipment from Los Alamos National Labs on March 27, 1999. During the WIPP operational phase but prior to the February 14, 2014 underground radiation release event, the CEMRC LWBC lab performed counts on 991 public volunteers. Following the February 14, 2014 underground radiation release event, the CEMRC LWBC lab performed *in vivo* measurements on 40 public volunteers. By comparing the results of the 40 individuals counted after the underground radiation event to the measurements compiled during the previous 16 years, we can conclude that there has been no negative health

effect detected on public citizens living in the surrounding areas of the WIPP facility as a result of the February 14, 2014 underground radiation release event.

CHAPTER 8 | VOLATILE ORGANIC COMPOUND

In addition to its WIPP-EM independent environmental monitoring program, the CEMRC also performs additional WIPP-related scientific activities as a contractor to the WIPP management and operations contractor Nuclear Waste Partnership, LLC (NWP). One of those contracted activities involves the analysis of air samples collected at the surface and from the underground of the WIPP facility for the determination of various gases including hydrogen (H), methane (M), and other volatile organic compounds (VOCs). The WIPP Hazardous Waste Treatment Facility (HWTF) permit, Attachment N, issued by the New Mexico Environment Department (NMED) under the Resource Conservation and Recovery Act (RCRA), mandates the monitoring of VOC emissions from mixed waste that may be entrained in the ambient air from the WIPP underground hazardous waste disposal units (HWDUs) to assure that VOC concentrations do not exceed regulatory limits, during or after disposal. Currently, nine (9) target VOCs are actively monitored as they represent 99% risk to safety due to air emissions while any other compounds consistently detected in air samples may be added to the list of compounds of interest. This section presents an overview of this activity; however, no sample data are presented as the data are considered to be proprietary to the NWP and DOE and are not subject to release by the CEMRC.

CHAPTER 9 | QUALITY ASSURANCE

This section summarizes the comprehensive quality assurance programs, which include various quality control practices and methods employed to ensure data quality. The programs are implemented through quality assurance plans designed to meet requirements of the American National Standards Institute. Quality assurance plans are maintained for all activities and certified auditors verify conformance. Samples are collected and analyzed according to documented standard procedures. Analytical data quality is typically verified by a continuing program of internal laboratory quality control, replicate sampling and analysis.

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Acronyms and Abbreviations

µBq	MicroBecquerel
µm	Micrometer
Am	Americium
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
Ba	Barium
Bq	Becquerel
C	Centigrade
Ca	Calcium
CAM	Continuous Air Monitor
Ce	Cerium
CEMRC	Carlsbad Environmental Monitoring & Research Center
CEMRP	Carlsbad Environmental Monitoring & Research Program
Cf	Californium
CFR	Code of Federal Regulations
CH	Contact-handled
Ci	Curie
cm	Centimeter
Cm	Curium
Co	Cobalt
Cr	Chromium
Cs	Cesium
DL	Detection Limit
DOE	U.S. Department of Energy
DOE/CBFO	U.S. Department of Energy/Carlsbad Field Office
EEG	Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
Eu	Europium
FAS	Fixed Air Samples
Fe	Iron
FP	Field Programs
g	Gram
HCl	Hydrochloric acid
$HClO_4$	Perchloric acid
HEPA	High Efficiency Particulate Air
HF	Hydrofluoric acid
HNO_3	Nitric acid
H_2O_2	Hydrogen Peroxide
HPGe	High Purity Germanium
I	Iodine
ID	Internal Dosimetry
Ir	Iridium
K	Potassium
km	Kilometer

L	Liter
LANL	Los Alamos National Labs
LDBC	"Lie Down and Be Counted"
m	Meter
MAPEP	Mixed-Analyte Performance Evaluation Program
mBq	MilliBecquerel
MDC	Minimum Detectable Concentration
MDL	Method Detection Limit
min	Minute
mL	Milliliter
Mn	Manganese
MTL	Minimum Testing Level
MTRU	Mixed Transuranic
Na	Sodium
NaOH	Sodium Hydroxide
Nd	Neodymium
NIST	National Institute of Standards and Technology
NMED	New Mexico Environment Department
NMSU	New Mexico State University
Np	Neptunium
NRIP	National Radiochemistry Intercomparison Program
NWP	Nuclear Waste Partnership
Pb	Lead
Pu	Plutonium
QA	Quality Assurance
QAP	Quality Assurance Program
QAPD	Quality Assurance Program Document
QC	Quality Control
Ra	Radium
RC	Radiochemistry
RH	Remote-Handled
Ru	Ruthenium
Sb	Antimony
SNL	Sandia National Labs
Sr	Strontium
Th	Thorium
TRU	Transuranic
Unc.	Uncertainty
U	Uranium
WHB	Waste Handling Building
WIPP	Waste Isolation Pilot Plant
WIPP-EM	Waste Isolation Pilot Plant Environmental Monitoring
Y	Yttrium
Zn	Zinc
Zr	Zirconium

CHAPTER 1

Introduction

The Waste Isolation Pilot Plant, commonly referred to as the WIPP, is a deep geologic transuranic (TRU) waste repository operated by the U.S. Department of Energy (DOE). The purpose of the repository is to emplace defense-related TRU wastes in the Salado Formation, a bedded salt formation approximately 655 m (2150 ft.) below the surface of the Earth. Located near Carlsbad, New Mexico, an area with approximately 40,000 people, the WIPP facility is the world's first underground repository permitted to safely and permanently dispose of TRU waste generated through defense-related activities and programs (see Figure 1-1). TRU waste is defined in the WIPP Land Withdrawal Act (LWA, Public Law 102-579) as radioactive waste containing more than 100 nanocuries (3,700 becquerels Bq/g) of alpha-emitting TRU isotopes per gram of waste, with half-lives greater than 20 years. Most TRU waste consists of contaminated industrial trash, such as rags and tools, sludges from solidified liquids, glass, metal, construction debris, and other materials. The upper waste acceptance criteria are <0.85 TBq/liter (<23 Ci/liter) of total activity, and <10 Sv/hr dose rate on contact with unshielded waste containers. Since the start of its operation in March 1999, more than 91,000 cubic meters of Cold-War legacy TRU waste have been removed from temporary locations around the nation and shipped to WIPP for permanent disposal. Currently, the WIPP is about half full in terms of its legally defined capacity.

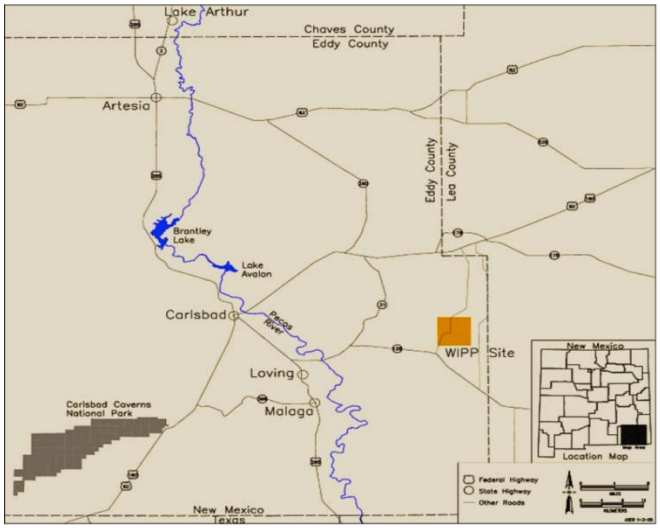


Figure 1-1: Location of the WIPP Site

Two types of TRU wastes are currently stored in the WIPP repository: (1) mixed transuranic waste (MTRU), meaning there is also hazardous waste components present and (2) non-mixed waste that contains only radioactive elements, mostly plutonium. The TRU waste is subdivided into contact-handled (CH) and remote-handled (RH) waste on the basis of the dose equivalent rate at the surface of the waste container. According to the legal definition, the term "contact-handled transuranic waste" refers to transuranic waste with a surface dose rate not greater than 200 millirem per hour. The term 'remote-handled transuranic waste' refers to transuranic waste with a surface dose rate of 200 millirem per hour or greater" (Congress, 1992). Contact-handled TRU waste typically emits relatively little gamma radiation; therefore, it can be handled directly by workers. Remote-handled TRU waste emits higher levels of gamma (penetrating) radiation; therefore, gamma rays represent the main radiological health hazard for workers handling RH-TRU waste. The WIPP became operational in March 26, 1999 for the disposal of TRU waste, and the WIPP first received mixed waste shipments on September 9, 2000. The WIPP mission is to dispose of 176,000 m^3 (6.2 million cubic feet) of contact-handled waste and 7,080 m^3 (250,000 cubic feet) of remote-handled waste which is equivalent to about 810,000 fifty-five gallon drums. Approximately 91,000 m^3 (319,000 cubic feet) of CH waste and 356 m^3 (12,572 cubic feet) of RH waste have been disposed of at the WIPP facility as of January, 2014. At least 66,200 m^3 of transuranic waste sit at several DOE sites, awaiting shipment to WIPP. The WIPP facility has remained closed to waste emplacement following an underground fire event that occurred on February 5, 2014 and an unrelated underground radiological release event that occurred nine days later on February 14, 2014. More information about the fire and radiological events can be found in the CEMRC 2014 annual report.

As shown in Figure 1-2, the WIPP repository layout currently has eight panels planned, each consisting of seven waste disposal rooms approximately 300 feet (91 meters) long ,33 feet (10 meters) wide, and 15 feet (4.5 meters) high. Seven of the panels have been excavated; and the first six have been closed and sealed from ventilation air. Waste disposal was in progress in the seventh panel at the time of the February 14, 2014 underground radiological event. In addition to panel eight, at least two additional waste storage panels are being planned.

The facility also consists of common drifts for access and ventilation to the disposal panels, four shafts connecting surface operations to underground emplacement activities and above ground waste receipt and handling facilities. The repository is ventilated by drawing in a large amount of outside air, unfiltered. Since the air in the repository exits to the surface through its exhaust shaft, this shaft is the

sole potential pathway for airborne radioactivity release from the WIPP during normal operations. The potential for release is mitigated by the presence of HEPA (High Efficiency Particulate Air) filters which are located at the surface. Additionally, continuous air monitors in the underground are used to control whether or not the ventilation air returning to the surface is passed through these large HEPA filter systems or is released directly to the atmosphere. The HEPA filtration system results in the removal of approximately 99.97% of radiological contamination from the underground WIPP exhaust air prior to being released to the environment; however, the major drawback of this system is that it significantly reduces the amount of airflow that is drawn through the repository at any one time. For example, prior to the February 14, 2014 underground radiological event, the amount of air moving through the WIPP underground was approximately 460,000 cubic feet per minute (cfm).

As a result of the February 14, 2014 underground radiological event and the potential for airborne contamination to be present in the WIPP underground air, the air must be directed through the HEPA filtration system before being released to the environment thereby reducing the amount of air moving through the WIPP underground to approximately 60,000 cfm or approximately one seventh of the pre-event level. In April 2016, a surface-mounted interim ventilation system (IVS) was installed and certified providing an additional 54,000 cfm of filtered air capacity to the WIPP underground ventilation system, raising the total available underground air flow to approximately 114,000 cfm. This increased underground ventilation was desperately needed to increase the number of personnel and diesel-powered equipment operating in the underground.

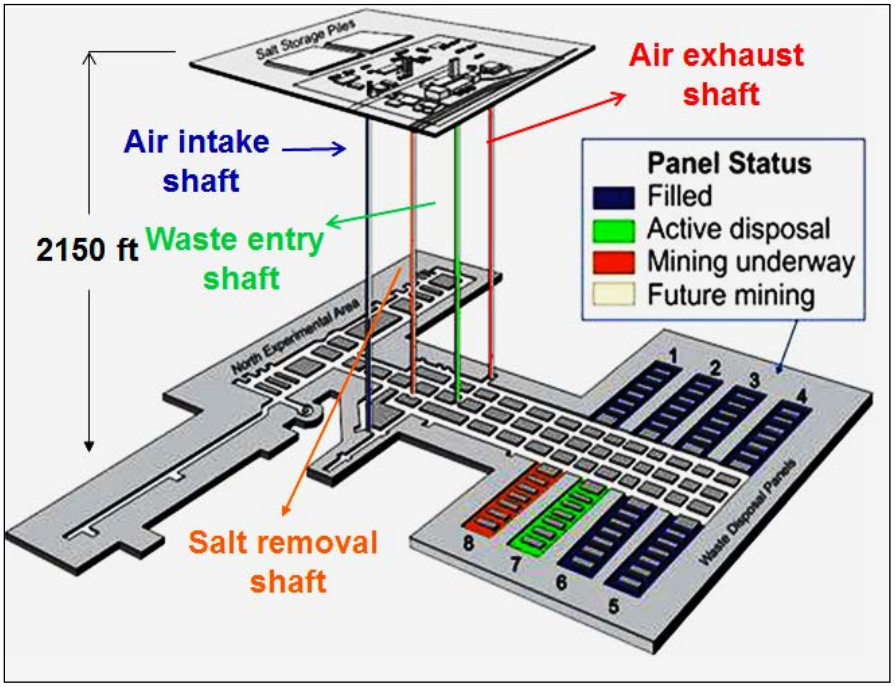


Figure 1-2: WIPP Layout

In terms of exhaust air monitoring, the WIPP facility operates three effluent air monitoring stations. These are known as Stations A, B, and C respectively. Each station is equipped with at least one fixed air sampler that collects particulates from the effluent air stream on a 47mm Versapore filter. Representative sampling is assured by system design. Under normal operating conditions (such as those encountered prior to the February 14, 2014 underground radiological event), unfiltered air is drawn through the repository and exhausted from the repository directly to the environment after passing through the Station A sampling port. Therefore, during normal operating conditions, the activities measured at Station A would represent the radiological activities present in the air within the repository and would be reflective of the level of contamination released directly to the environment. However, once contamination is detected in the underground by a continuous air monitor (such as what occurred during the radiological event on February 14, 2014), the system shifts into "filtration mode" thereby significantly lowering the quantity of air being drawn through the repository and directing this exhaust air through the bank of surface-mounted HEPA filters before being released into the environment.

The Station B fixed air sampler collects the air downstream of the bank of HEPA filters, including the newly operational IVS, and is representative of the level of contamination ultimately released into the environment while operating in filtration mode. It is important to note that the WIPP exhaust air ventilation system has been operating in filtration mode since the underground event occurred on February 14, 2014. Station C is used to sample the exhaust from the Waste Handling Building (WHB) where air exhausted from the WHB passes through double HEPA filters before being vented to the environment. The waste container is the primary confinement barrier in the WHB; while negative building pressure and HEPA filtration provide secondary confinement to potential radiological contamination. The CEMRC, like the New Mexico Environment Department (NMED) and the WIPP contractor (NWP), has its own collection ports at Station A and Station B on which it collects exhaust air samples in order to perform its independent analyses. Prior to the February 14, 2014 underground release event, the CEMRC did not sample Stations B or C unless there was an indication of a release-detection by a CAM located in the underground or in the WHB. However, since the underground radiological release event, the CEMRC has been performing expedited sampling and analysis of Station A and B filters respectively.

WIPP History

The WIPP site is an essential effort in support of cleaning up the nation's TRU waste which is currently stored at several federal facilities around the country. The history of the WIPP goes back to 1957, when the National Academy of Science recommended bedded salt formations as the optimal geologic formation for the underground disposal of radioactive waste. Salt deposits were selected as the host for the disposal of nuclear waste for the following reasons: 1) Most deposits of salt are found in stable geological areas with very little earthquake activity, assuring the long-term stability of a waste repository. 2) Salt deposits

also demonstrate the absence of water that could move waste to the surface. If water had been present in the past or was currently present, it would have dissolved the salt beds. 3) Salt is relatively easy to mine in comparison to many other geologic formations. 4) Finally, rock salt heals its own fractures because it behaves plastically under lithostatic pressure, constantly moving to fill voids, gaps, or cracks. The impetus to go forward with the project developed in 1969-1970 when a series of fires at the DOE Rocky Flats facility near Denver, Colorado caused an airborne release of plutonium. At that time, DOE agreed to stop storing plutonium wastes at Rocky Flats and began shipping TRU wastes to the Idaho National Engineering and Environmental Laboratory in southeastern Idaho. Idaho was promised that the wastes would only be stored for ten years in Idaho while the search began for a site where these wastes could be permanently disposed. DOE had previously evaluated a site near Lyon, Kansas, in an abandoned salt mine, but strong political opposition by state officials and a combination of numerous boreholes and large volumes of water "lost" in fractures in the salt forced them to look elsewhere. They considered several New Mexico sites, eventually settling on the current site near Carlsbad. The encouragement of local politicians and businesses, the depressed economic conditions in that part of the state at the time, and a ready labor force already trained in what was needed to construct the repository, were all important factors in bringing WIPP to this area. In 1979, Congress authorized the construction of the WIPP facility, and the DOE constructed the facility during the 1980s. In late 1993, the DOE created the Carlsbad Area Office (CAO), subsequently re-designated as the Carlsbad Field Office (CBFO), to lead the TRU waste disposal effort. The CBFO coordinates the TRU program throughout the DOE complex.

On March 26, 1999, the WIPP facility received its first waste shipment from the Los Alamos National Laboratory in Los Alamos, New Mexico.

Environmental Setting of the WIPP

The WIPP facility is located in Eddy County in Southeastern New Mexico, approximately 26 miles east of Carlsbad. The facility is located on a sandy plain at an elevation of 1,040 m (3,410 ft) above sea level. Prominent natural features near the facility include Levingston Ridge and Nash Draw, about 8 km (5 miles) west of the facility. Nash Draw is a shallow, dog–bone shaped drainage course between 8.5 miles and 11 miles in width, characterized by surface impoundments of brine water. Livingston Ridge is a bluff that marks the eastern edges of Nash Draw. Other prominent features of the region include the Pecos River, located about 22 km (14 miles) west of the facility, and the Carlsbad Caverns National Park, located about 68 km (42 miles) west-southwest of the WIPP facility.

The majority of the local population within 80.5 km (50 mi) of the WIPP site is concentrated in and around the communities of Carlsbad, Hobbs, Eunice, Loving, Jal, Lovington, and Artesia, New Mexico. According to 2010 census data, the estimated population within this radius is 88,952. The nearest community is the village of Loving (estimated population ~2000), 29 km (18 mi) west-southwest of the WIPP site. The nearest

major populated area is Carlsbad, 42 km (26 mi) west of the WIPP site. The 2010 census reported the population of Carlsbad as 26,138.

The transient population within 10 miles of WIPP is associated with ranching, oil and gas exploration/production, and potash mining. Three ranchers (Mills, Smith, and Mobley) have property in the vicinity of the WIPP facility. The Mills ranch headquarters is located 5.6 km (3.5 miles) south-southwest of the facility center, the Smith headquarters is 8.8 km (5.5 miles) west-northwest of the facility, and the Mobley ranch is 9.6 km (6 miles) southwest of the facility.

The climate in the region of the facility is semi-arid with an average annual precipitation of 280 to 300 mm (11 to 13 inches) with much of the precipitation falling during intense thunderstorms in the spring and summer seasons. Winds are generally from the southeast with an average speed of 14 km/hour (8.8 miles/hour).

Although there are no dairies near the WIPP facility, a large amount of alfalfa is grown in the Pecos Valley between Roswell and Malaga, New Mexico. The alfalfa crop is used in cattle feeding operations mainly in New Mexico and Texas. In addition to alfalfa, cotton and pecans are the other major crops grown in the Pecos Valley region.

Background Radiation

There are several sources of naturally occurring radiation including: cosmic and cosmogenic radiation (from outer space and the earth's atmosphere), terrestrial radiation (from the earth's crust), and internal radiation (naturally occurring radioactive material in our bodies, such as potassium or ^{40}K). The most common sources of terrestrial radiation are uranium, and thorium, and their associated decay products. Radon gas, a decay product of uranium, is a widely known naturally occurring terrestrial radionuclide. Another source of terrestrial radiation is ^{40}K. While not a major radiation source, the presence of ^{40}K in the southeastern New Mexico environment may be due to the deposition of tailings from local potash mining. In addition to natural radioactivity, small amounts of radioactivity from aboveground nuclear weapons tests that occurred from 1945 through 1980, and the 1986 Chernobyl and 2011 Fukushima nuclear accidents are also present in the environment. Together, these sources of radiation are called "background" radiation (Figure 1-3).

Naturally occurring radiation in the environment can deliver both internal and external doses to humans. An internal dose is received as a result of the intake of radionuclides through ingestion (consuming food or drink containing radionuclides) and inhalation (breathing radioactive particulates). An external dose can occur from immersion in contaminated air or deposition of contaminants on surfaces. The worldwide average natural dose to humans is about 2.4 millisievert (mSv) per year, which is four times more than the worldwide average artificial radiation exposure. Site-specific background gamma measurements on the surface, conducted by Sandia National Laboratories (SNL), showed an

average dose rate of 7.65 microrem per hour (Minnema and Brewer, 1983), which would equate to the background gamma radiation dose of 0.67 millisieverts (mSv or 67.0 mrem) per year. A comprehensive radiological baseline study conducted before WIPP facility disposal operations began was also documented in *Statistical Summary of the Radiological Baseline for the Waste Isolation Pilot Plant* (DOE/WIPP-92-037), which provides the basis for environmental background comparison after WIPP facility disposal operations commenced.

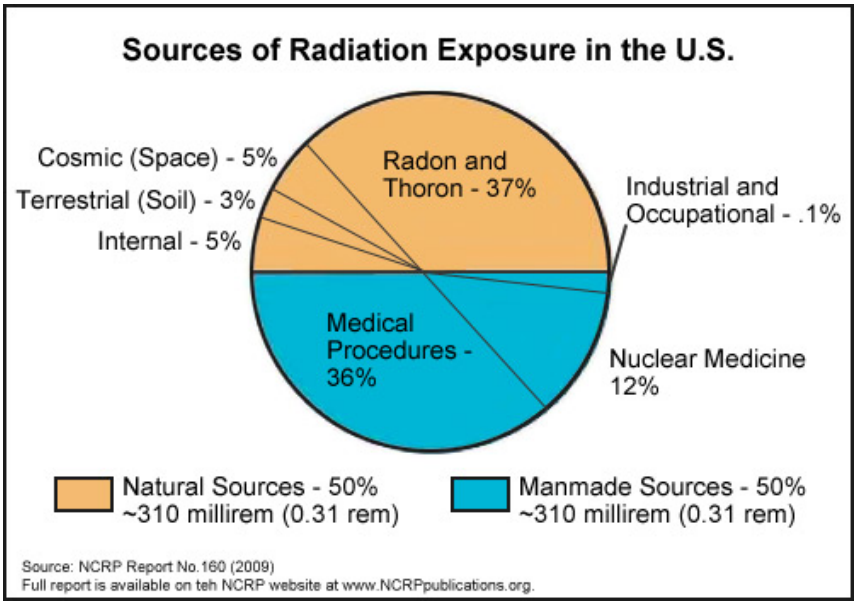


Figure 1-3: Source of Radiation Exposure

Radiological Environment around WIPP

The radiological environment near the WIPP site includes natural radioactivity, global fallout from nuclear weapons tests and, potentially, a local source of anthropogenic (man-made) radioactive contamination remaining in the area from Project Gnome, an underground nuclear test conducted by the U.S. Atomic Energy Commission. In 1961, the surface area of the Gnome site was contaminated with fission radionuclides when an underground test of a 3.3-kiloton ^{239}Pu device vented radioactive materials to the surface (USAEC, 1973). The Gnome project was part of the Plowshare Program intended to demonstrate the peaceful use of atomic energy. The Gnome site is located approximately 8.8 km (5.5 miles) southwest of the WIPP site.

Clean-up efforts at this site have been carried out in several campaigns since that time and the surface contamination is now well below the risk-based action levels. However, despite these cleanup efforts, ^{137}Cs and plutonium have been detected by the CEMRC in some samples of surface soils collected at the Gnome site. While the transport of these

contaminants from the Gnome site to the WIPP remains a possibility during high wind seasons (Stout and Arimoto, 2010); a review of more than fifteen years of monitoring data and the activity levels detected, as well as their atomic ratio measurements, suggest that pre-release-event plutonium and americium in aerosol and soil samples collected near the WIPP facility mainly represent redistributed global fallout from non-Gnome related incidents.

Independent Environmental Monitoring Program – An Overview

The success of any nuclear facility is strongly tied to the degree of public acceptance and understanding that is established. The WIPP is an example where public engagement has constantly been provided at a high level. From the standpoint of addressing the operational and environmental risks, as well as allaying public concerns, the WIPP has endured extensive human health and environmental monitoring activities. In addition to the regulatory compliance monitoring required by the repository licensee, and also conducted by the State of New Mexico and previous entities, the local community demanded the implementation of a sophisticated environmental monitoring program carried out by an independent academic institution that would emphasize a science-based program, rather than one focused on compliance.

Many factors contributed to the success of this project during its first almost 15 years of operations. An important factor is the local acceptance engendered by an independent environmental monitoring program in the vicinity of the WIPP that began before and continues after the WIPP began receiving nuclear waste. This independent monitoring is being conducted by the Carlsbad Environmental Monitoring and Research Center (CEMRC), which is associated with the New Mexico State University system. The CEMRC is funded by the DOE through a financial assistance grant process that respects its independence in carrying out and reporting the results of environmental monitoring activities conducted at and near the WIPP site. Unlike most environmental programs which only monitor down to compliance or action levels, the mission of the CEMRC is to monitor to below background levels, as the public needs to know what is truly happening in the environment and what effect WIPP operations may have on their lives and health. As a result, some approaches the CEMRC has undertaken to accomplish this mission includes increasing counting times on alpha and gamma spectroscopy systems in order to routinely achieve the lower detection limits for alpha and gamma-emitting radionuclides or by adopting a 12-detector array for *in vivo* bioassay in order to observe the 17.1 keV spectrum thereby indicating the presence of Pu in the lung. The CEMRC has been conducting independent health and environmental monitoring in the vicinity of WIPP since 1995 and has made the results easily accessible to all interested parties. Public access to the monitoring data and their ability to directly participate in CEMRC's whole body counting program provides a key element of trust and transparency for the public.

Radionuclides present in the environment, whether naturally occurring or anthropogenic (human-made), may contribute to radiation doses to humans. Therefore, environmental monitoring around nuclear facilities is imperative to characterize radiological baseline conditions, to identify any releases, and to determine their effects, should they occur. The purpose of the CEMRC WIPP-EM radiological environmental monitoring program is to measure radionuclides in the ambient environmental media. These data allow for a comparison of sample data to results from previous years and to historical baseline data, to determine what impact, if any, the WIPP is having on the surrounding environment. Radiological monitoring at the WIPP site includes sampling and analysis of air (both WIPP underground exhaust and ambient air), drinking water, surface water, sediment and soil. Additionally, the scope of the CEMRC WIPP environmental monitoring activities is broad and includes radiological screening of local citizens (whole body counting for the public) as well as routine sampling of water (including both drinking water and surface waters), soil and sediment for hazardous non-radiological constituents. Routine reporting is done annually and published on the CEMRC website (www.cemrc.org). Non-routine results, if they occur, are reported as they are found after review and interpretation. One of the CEMRC's core competencies is to detect and to report radioactive contaminant levels, even those below the regulatory requirements, as soon as possible and to disseminate this information to the public in a timely and understandable nature. The CEMRC program has capabilities to detect radionuclides rapidly in case of accidental releases from the repository or other portions of the facility during waste handling/waste emplacement operations.

The CEMRC's environmental monitoring activities generally fall into three categories: collecting environmental samples and analyzing them for a variety of contaminants, evaluating whether WIPP-related activities cause any environmental impacts, and taking corrective action when an adverse effect on the environment is identified. The current CEMRC operational environmental sampling and analytical plan is detailed in previous CEMRC annual reports. The four major elements of the program include WIPP exhaust air, ambient air, drinking water and human monitoring. For these four elemental areas, sample collection and analyses is more frequent whereas the sampling and analyses frequencies for other environmental media such as soil, sediment and surface water are generally acquired and analyzed once every two years on an alternating basis.

For ambient air analyses, the CEMRC operates four ambient air samplers in and around the WIPP site and two ambient air samplers in the two closest municipalities nearest the WIPP facility (the Village of Loving and the City of Carlsbad). The fourth high-volume sampling station located on the east side of the WIPP facility was deployed in calendar year 2017; therefore, aerosol sampling at this sampling station had not begun at the time this document was prepared. The ambient air monitoring sites nearest the WIPP facility are located in the most prevalent wind directions from the facility, whereas the ambient air monitoring sites in Loving and Carlsbad are located on Village of Loving owned property and at the CEMRC facility primarily as a matter of convenience and cost. The primary purpose of

ambient air monitoring is to obtain baseline data and to determine whether the nuclear waste handling and storage operations at the WIPP have released radionuclides into the environment around the WIPP or its two closest municipalities.

Public drinking water samples are sampled annually from six drinking water sources in the region of the WIPP. These sampling locations are not likely to be affected by any WIPP radioactivity releases; however, because water is a primary vector in the food chain, the samples are collected and analyzed on a regular basis. As with community air sampling, the absence of WIPP radionuclides in drinking water samples provides additional public assurance associated with the WIPP and WIPP-related activities.

As mentioned previously, WIPP exhaust air is the most likely pathway for accidental radioactivity releases from the WIPP. Accident release scenarios are postulated in the WIPP Safety Analysis Report (USDOE WIPP 1997a). If an underground operations accident were to occur, air samples would be collected from Stations A and B which represent the final release points of the underground repository exhaust ventilation system. Consequently, the CEMRC collects filter(s) from Station A and B each day and then performs a gross alpha/beta screening process on the individual filters for the presence of radioactive contamination. This daily sampling process allows for a careful study of the variability of radioactivity background and trends. Following the gross alpha/beta screening process, the CEMRC then performs the more sensitive radiochemical analyses on the composited weekly and/or monthly filters to identify specific radioactive isotopes.

From time to time, soil, sediment and surface water samples are also collected and analyzed to verify radionuclides concentrations and to establish the variability of background radioactivity. In addition, soil samples were previously collected from selected areas and control locations outside of the WIPP land withdrawal area, such as the Gnome site, and were analyzed for the presence of radionuclides thereby creating the ability to identify localized surface contamination from non-WIPP related activities. The results of the Gnome study are presented in the 2005/2006 CEMRC Annual Report.

Since the inception of the CEMRC WIPP environmental monitoring program, the CEMRC has been monitoring the concentration of plutonium (Pu) and americium (Am) in the area around the WIPP site for many years, as isotopes of these elements are the major radioactive constituents likely to be found in the TRU waste. Additionally, uranium isotopes (^{238}U, ^{235}U, ^{234}U), prominent alpha-emitting radionuclides in the natural environment, and cesium (^{137}Cs), a potentially important beta and gamma-emitting constituent of the TRU waste disposed at WIPP, have also been the subject of background studies conducted by the CEMRC at WIPP prior to 1999 and continue to be monitored. Cobalt (^{60}Co) and other gamma-emitters, though not major constituents of the TRU waste, are also monitored. Lastly, potassium (^{40}K), a natural gamma-emitting radionuclide, which is ubiquitous in the earth's crust, is also monitored because of its possible enhancement in southeastern New Mexico due to the abundance of potash mining in the area.

In addition to the monitoring of environmental media (air, soil, drinking water, and surface water/sediment) in the vicinity of the WIPP site, the CEMRC also performs routine monitoring of adult residents living within a 100-mile radius of the WIPP facility for the presence of gamma-emitting radioisotopes through its *Lie Down and Be Counted* (LDBC) program. The LDBC project serves as a component of the WIPP-EM program that directly addresses the general concern about personal exposure to contaminants shared by residents who live near DOE sites. As in other aspects of the WIPP-EM program, *in vivo* bioassay testing was used to establish a baseline profile of internally-deposited radionuclides in a sample of local residents before disposal phase operations began, and has continued into the disposal phase to the present. The sampling design includes the solicitation of adult volunteers from all segments of the community, with sample sizes sufficient to meet or exceed a 15% range in margin of error for comparisons between major population ethnicity and gender categories as identified in the 1990 U.S. census. Radiobioassays of the original volunteer cohort have been ongoing since July 1999. New volunteers continue to be recruited each year to establish new study cohorts and to replace volunteer attrition. While the passage of time and the overall success of the WIPP have historically made it difficult to attract new volunteers to the LDBC program, the February 14, 2014 event provided renewed interest on behalf of resident volunteers. Results of the LDBC, both historically and those screened between the February 14, 2014 underground radiation event to December 30, 2016 are reported herein. Also, as a result of the February 14, 2014 radiation release event, the age for public volunteers was reduced from 18 years of age to 13 years of age in order to accommodate requests by the DOE and interested constituents.

The Recovery from the 2014 Fire and Radiological Release Events at the Waste Isolation Pilot Plant

After months of investigations into the cause of the underground truck fire and the underground radiological release event, the U.S. Department of Energy released a recovery plan at the end of September, 2014 (WIPP-Recovery Plan, Sept, 2014) that outlines the steps necessary to clean up and to resume limited waste emplacement operations by early 2017. As can be seen in Figure 1-4, decontamination of work areas is a key element of the WIPP Recovery Plan as a portion of the underground area was heavily contaminated by the February 14, 2014, underground radiation release event. Other parts of the recovery plan include: (1) continued HEPA filtration of underground exhaust air through an expanded interim ventilation system (IVS), (2) expedited closure of Panel 6, where a few hundred suspect waste drums assumed to contain the same type of nitrate salt-bearing waste that led to the underground radiological release event are located, and (3) expedited closure of Room 7 in Panel 7, the location of the ruptured waste drum where the February 14, 2014 underground radiation release event occurred. During 2016, several notable recovery-related activities were completed at the WIPP facility. The interim ventilation system (IVS) was installed and is in operation. Similarly, progress has been made on the supplemental ventilation system. Once completed and on-line, the combined WIPP exhaust circuit, interim

and supplemental ventilation systems (SVS) will provide a total of 5,100 m^3 per minute (180,000 cfm) of airflow in the underground, a sufficient ventilation flow needed to support limited waste emplacement operations and to resume underground mining activities. Airflow from the IVS and WIPP exhaust air will continue to be passed through HEPA filters prior to discharge; whereas airflow from the SVS will comprise a "clean" circuit and will be exhausted through the WIPP Salt Shaft. A new permanent ventilation system (PVS, replacement to the current ventilation system) is being designed to enable WIPP underground operations to return to full operation, unrestricted by ventilation rates. Although estimates vary, the new permanent ventilation system is expected to generate flow rates up to 15,000 m^3/min (540,000 cfm). However, this new permanent ventilation system is estimated to cost several hundred million dollars and is not anticipated to be completed until 2021.

The 2014 underground radiological release event has changed WIPP from a "clean" nuclear facility to one that simultaneously operates in contaminated and uncontaminated areas for the foreseeable future. As a result of the underground radiological release event, portions of the WIPP underground - primarily those portions along the ventilation path from the location of the incident to the top of the exhaust shaft continue to exhibit varying levels of contamination. Recovery activities involving decontamination of selected underground areas including the pathway from the Waste Hoist to the entrance of Panel 7 and all areas south of S2520 were completed by September 2015 which served to reduce the level of restrictions for certain areas and lowered the personnel protective equipment (PPE) required in a significant portion of the underground. It is important to note that a vast majority of the underground was not affected by the radiological event. Additionally, radiological decontamination activities are not expected to be performed in technically challenging areas such as the exhaust shaft (655 vertical meters). As waste emplacement operations resumed in the WIPP underground in early 2017, there are now both clean and contaminated areas present within the WIPP disposal area.

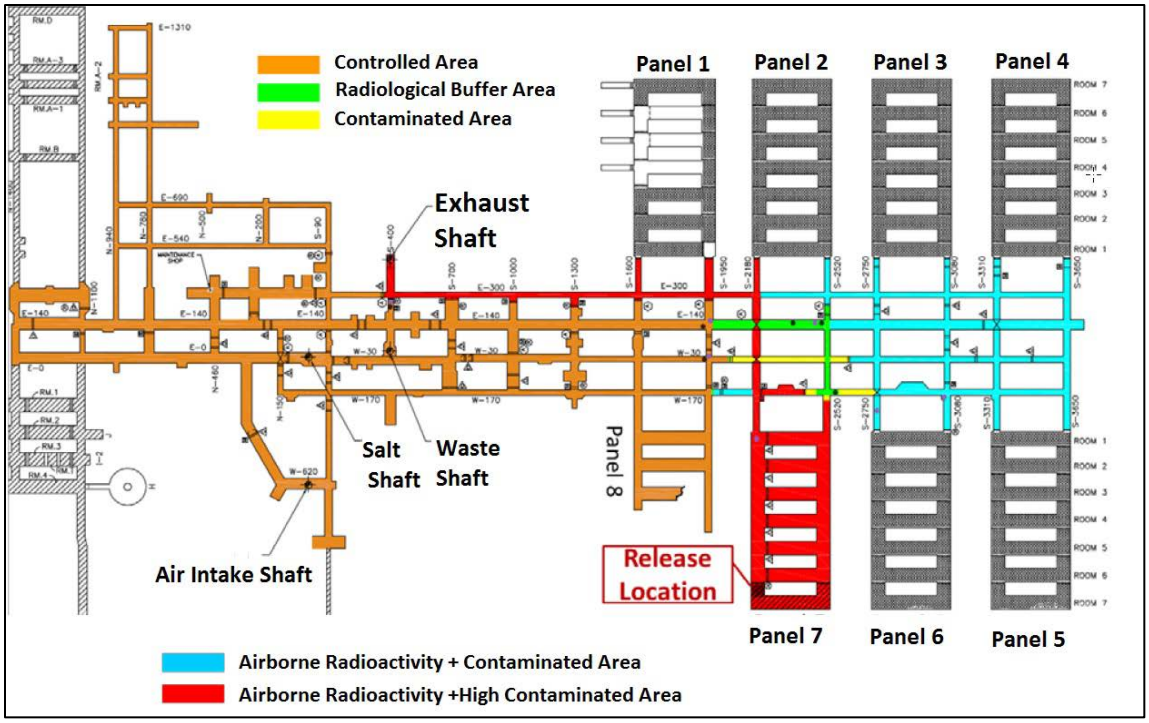


Figure 1-4: Radiological Contamination Map of WIPP Underground
(Source: Department of Energy, Carlsbad Field Office

In response to the February 14, 2014 underground radiological release event, the CEMRC has continued its efforts to conduct accelerated analyses of the underground filters collected from Stations A and B, surface ambient air samples, and other environmental samples collected in the vicinity of the WIPP site. This report summarizes the samples collected and analyzed during the calendar year 2016 and, in addition, presents an evaluation of approximately three years of environmental monitoring data that informed the public pertaining to the levels of radiation that escaped to the environment from the WIPP underground during the February 14, 2014 underground radiation release event. As reported in the 2014 annual report, the ongoing data from this year's monitoring activities suggest that the 2014 underground radiological release event resulted in the release of very low amounts of contaminants from the WIPP underground and confirms that the escaped contaminants did not harm anyone nor did they pose any long-term consequence to the environment. In terms of radiological risk at or in the vicinity of the WIPP site, the increased risk from the WIPP releases is exceedingly small, approaching zero.

CHAPTER 2

WIPP Underground Air Monitoring

The WIPP repository is ventilated by drawing ambient air down three widely spaced access shafts (air intake shaft, salt shaft, and waste handling shaft) to the underground and exhausting it out a single fourth shaft (exhaust shaft). Sampling the exhaust shaft air, at a point named Station A, allows an evaluation of the frequency and amount of any radioactivity released from or through the repository. The effluent studies at Station A are a major component of the WIPP Environmental Monitoring (WIPP-EM) program. Sampling operations at Station A provide a way to monitor for releases of radionuclides and other substances in the exhaust air from the WIPP. In addition, if radioactive materials were to be released from the facility, detection at Station A would precede observation in the local population or environment.

Station A is an above ground sampling platform that collects particulates from unfiltered air exhausted from the repository and funnels air either directly to the environment or into a high efficiency particulate air (HEPA) filter bank (Figure 2-1). A second sampling station, referred to as Station B, samples the underground exhaust air after HEPA filtration and, sometimes, non-filtered air during maintenance-related activities (Figure 2-2). While in filtration mode, Station B becomes a post-filtration sampler analyzed by the CEMRC and other entities such as the New Mexico Environment Department (NMED) and the WIPP Environmental Services group (WIPP Labs). When not in filtration mode Station B is not sampling WIPP exhaust air, hence the CEMRC only performs analyses on Station B filters when the system is operating in filtration mode. An Overview of the WIPP ventilation system and normal underground air flow are depicted in Figure 2-3.

Overview of CEMRC's Station A Monitoring Program

As mentioned previously, the aerosol studies at Station A are a major component of CEMRC's WIPP environmental monitoring Program. Station A is used for exhaust air compliance monitoring purposes and the aerosol sampling systems deployed there were designed to collect ≥ 50 % of the 10 µm diameter aerosols under the expected range of exhaust air velocities. CEMRC commenced sampling of the WIPP exhaust air on 12 December, 1998. Aerosols samples are collected from within the Exhaust shaft using a cylindrical shrouded probe commonly referred to as a fixed air sampler or FAS. The airflow through the FAS is approximately 170 liters per minute (~6 cfm) flow rate.

There are actually three shrouded-probe aerosol samplers located at Station A along with three separate sampling skids denoted A1, A2, and A3 (Figure 2-4). The airstream sampled by each skid is split among three legs such that three concurrent samples can be collected from each skid. On January 15, 2000, the CEMRC sampling operations were moved from the original sampling point at Skid A2 (west skid) leg 1 to Skid A1 (east skid) leg 2 to facilitate more direct data comparisons among the three organizations sampling the effluent air. Since that time all groups, CEMRC along with WIPP Labs and the Environmental Evaluation Group (EEG), later replaced by the NMED, have sampled from the same skid. In April 2001, primary sampling operations were transferred from Skid A1 to Skid A3 (south skid) to reduce problems associated with water infiltration into the exhaust shaft.

During normal sampling activities, the FAS sample filters are changed daily except during holidays, when a filter may run for multiple days. The aerosol sampling operations at Station A have at times been hampered by filter clogging, and during one interval (January 24, 2000 to November 28, 2001), CEMRC and the other organizations changed filters twice daily Monday through Friday. Daily sampling resumed when mass concentrations decreased and flow rates improved. Occasionally, however, more than one sample per day is still collected when the flow rate on any of the sampler legs drops below 0.06 m^3 (~1.8 cfm). If this occurs, a low-flow alarm on the sampler is activated and the filters are changed as needed by WIPP radiological control technicians.

Quarterly composites were initially used for the determination of actinide activities, but monthly compositing was implemented by the CEMRC in July of 2004 for better comparison with other groups who use monthly composites. These monthly composites are used for the determination of gamma emitter radionuclides as well. Only one half of the composite sample is normally used for the determination of the actinide activities. The remaining aliquot is archived. For some time following the radiation release event, filters at station A were changed every 8 hours and measurements were performed on each filter and later on daily combined filters, by CEMRC, depending on the levels of contamination found. As airborne concentrations receded, the frequency of filters collected at station A was reduced to daily, but actinide measurements continue to be performed on weekly composite samples.

The sensitivity of the monitoring program at Station A was dramatically demonstrated in January 2001 when CEMRC found elevated gross beta radioactivity in the FAS sample filters. Further investigations eventually traced the source of the beta emitter(s) to the discharge of a fire extinguisher underground, but the incident was more notable because it demonstrated for the first time the ability of the monitoring system to detect a non-routine event. A second incident occurred when scientists from CEMRC reported that they had detected a small quantity of Pu in a composite aerosol sample from the second calendar quarter of 2003. This discovery was later corroborated by both EEG (Environmental Evaluation

Group) and the WIPP's own monitoring organization, WIPP Labs, through the analyses of samples that were independently collected and analyzed. The detection of plutonium in the exhaust air led to the issuance of a CEMRC report to the U.S. Department of Energy and a briefing presented to the New Mexico Environment Department. The activity was extremely low and well within historic background, but indicated the ability of the monitoring program to detect radionuclides of interest at any level above the MDC. In 2008, 2009, and 2010, CEMRC again detected a small quantity of plutonium in composite aerosol samples similar to the 2003 detection, also corroborated by WIPP Labs. Such small occasional detections are to be expected because of global distribution of plutonium in the environment and the 2003, 2008, 2009 and 2010 positive detections provide a baseline for future events.

Sample Collection

As was mentioned previously, unfiltered exhaust air from the underground repository is sampled at station A. The daily Station A air samples are collected on 47 mm diameter membrane filters (Versapor® membrane filter, PALL Corporation, pore size 3 µm) with the use of a shrouded probe, commonly referred to as a fixed air sampler or FAS. As shown in Figures 2-4 and 2-5, each probe has a transfer line running to each of three sampling legs; thus a total of three concurrent samples can be collected from each FAS, one each for the CEMRC, the site contractor, WIPP Labs and the NMED. A previous test of the probes confirmed that this configuration allows for the collection of representative air samples (Gross et al., 2011). Under normal (non-filtration) operating conditions, each day approximately 81 m^3 (2,875 ft^3) of air is filtered through each of the Versapor filters at Station A. Typically, a CEMRC Field Program technician collects samples at Station A daily; however, as mentioned above, occasionally more than one sample per day is collected if the flow rate on any of the sampler legs drops below 0.06 m^3.

Figure 2-1: Location of Station A

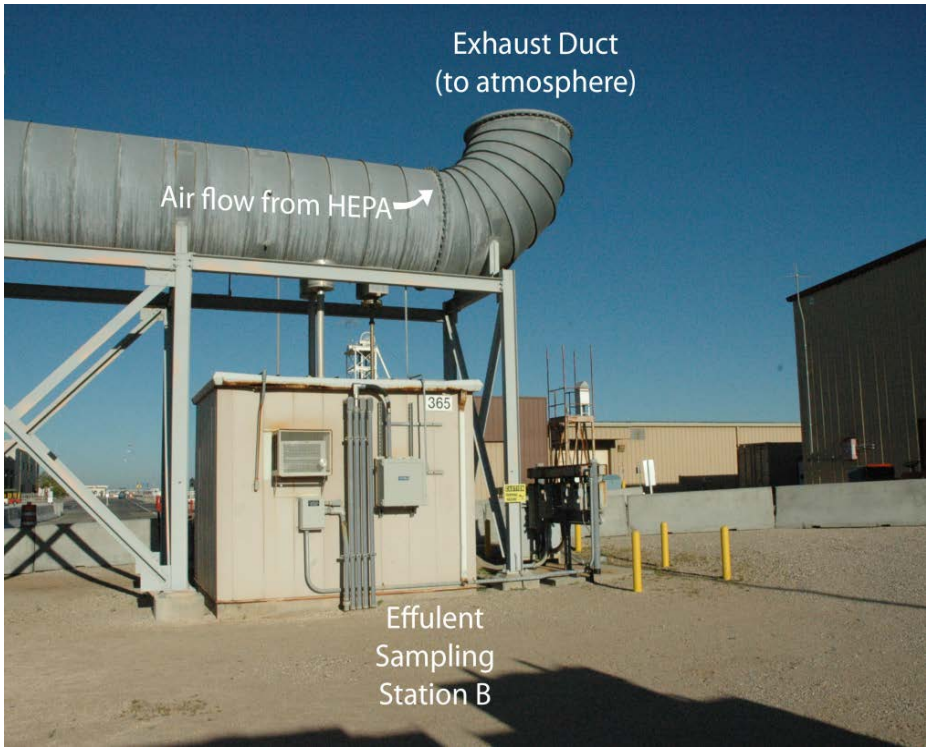


Figure 2-2: Location of Station B

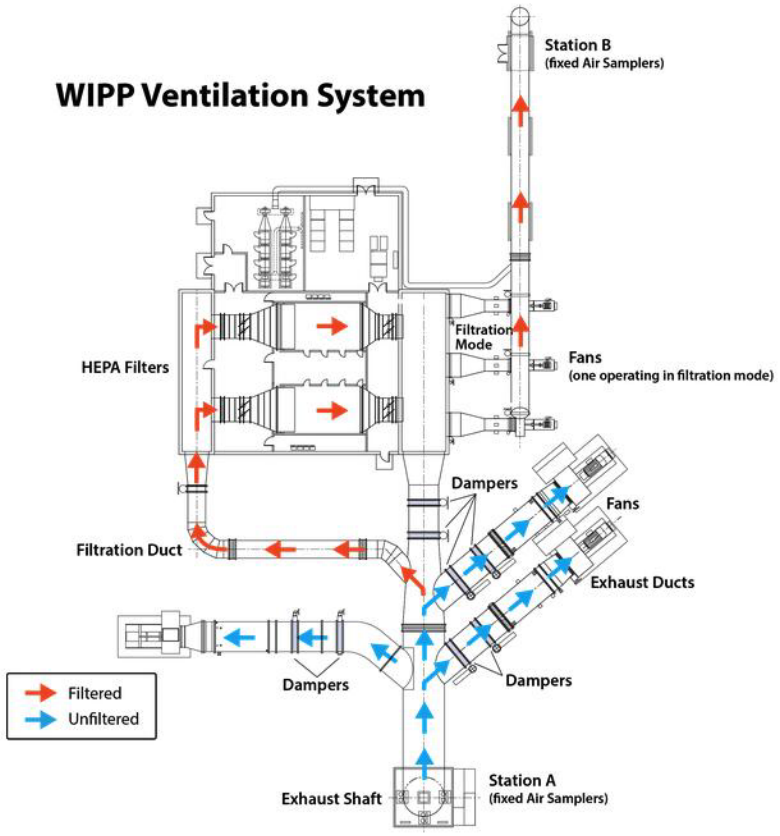


Figure 2-3: Overview of WIPP Ventilation System

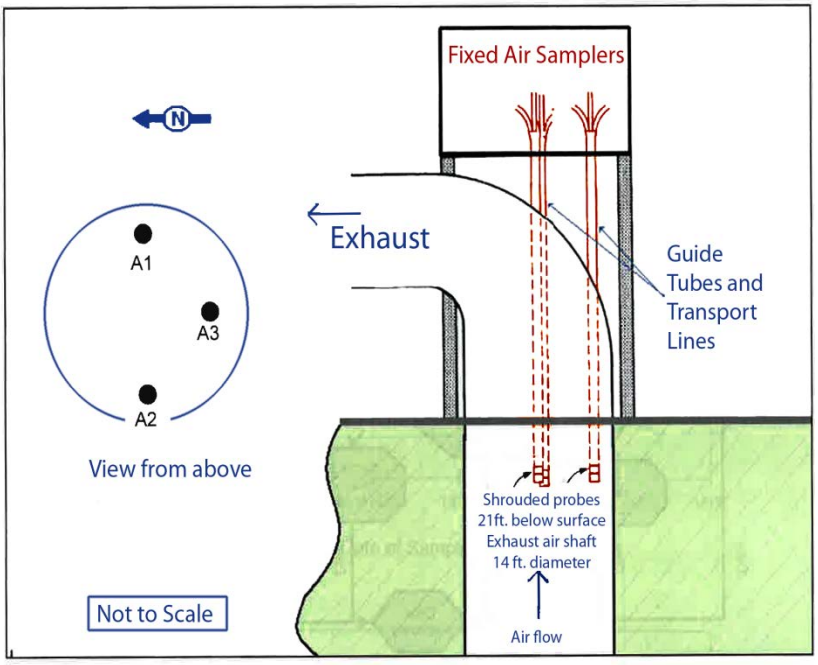


Figure 2-4: Overview of Station A

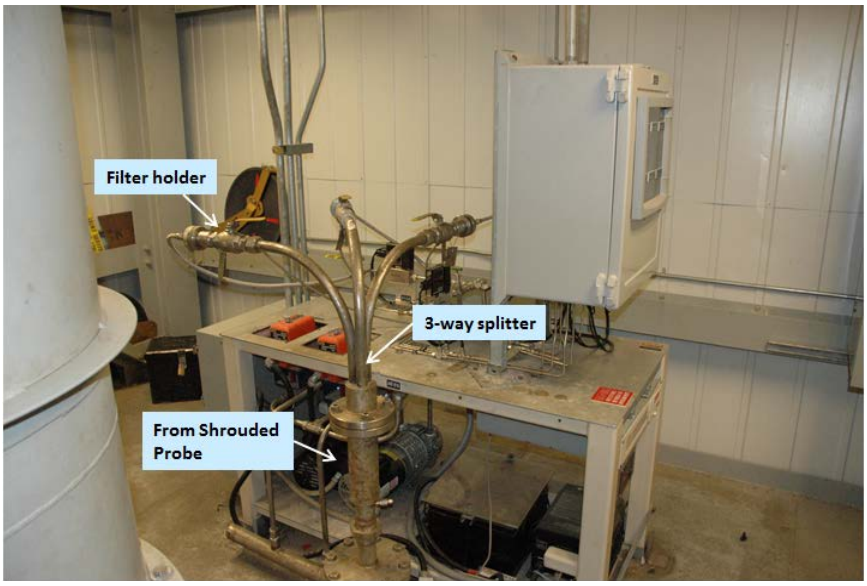


Figure 2-5: Fixed Air Samplers at Station A

Prior to the February 14, 2014 underground radiation release event at the WIPP, weekly filter samples were typically collected by the CEMRC at station B where approximately 583 m^3 (20,603 ft^3) of air is filtered through each of the Versapor filters each week. WIPP exhaust air samples were combined monthly for Station A for analysis by CEMRC and WIPP Labs, and quarterly for Station B for analysis by WIPP Labs. For some time following the February 2014 underground radiation release event, filters at station A and B were changed every 8 hours and measurements were performed on each individual filter initially and eventually were performed daily on combined filters, by the CEMRC, depending on the levels of contamination found. As airborne concentrations receded, the frequency of filters collected at station A and station B were reduced to daily; however, actinide measurements continued to be performed on weekly composite samples from Station A and on monthly composite samples for Station B during 2016. Since the repository continues to operate in filtration mode, CEMRC technicians continue to collect and analyze Station B samples daily.

Sample Preparation and Analysis

Gross Alpha and Beta Analysis

Once the samples are collected from the site and returned to the laboratory, individual filters are desiccated for a minimum of 48 hours to ensure that any moisture on the filters is evaporated and to ensure complete decay of the immediate daughter products of ^{222}Rn and ^{220}Rn. Once dried, the filters are then weighed to determine mass loading concentrations. Following the desiccating and weighing process, the Station A and B filters are counted for gross alpha and beta activities on a Protean MPC 9604 low background gas proportional counter for 1200 minutes.

In preparation for gross alpha/beta counting, the filter is centered on a stainless steel planchet. The standard planchets for the alpha and beta were prepared from certified solutions of ^{239}Pu and ^{90}Sr/^{90}Y obtained from Analytics, Inc. (Atlanta, GA, USA). In the time period immediately following the February 14, 2014 underground radiation release event, the planchet was counted on a low-background gas proportional counter for 180-300 minutes. Later, as airborne concentrations continued to recede, beginning July 2014, filters from Stations A and B were counted for 1200 minutes. The sample detectors are gas flow window type counters with an ultra-thin window. The counting gas was P-10, which is a mixture of 90% argon and 10% methane. The operating voltage on the detector was selected as 1,450V. All samples flow at a pressure slightly exceeding atmospheric. The window consists of 80 μg/cm Mylar foil with a tint of evaporated Au. The small size of the detector and the guard ensure a very low background in this system, ~0.5 and ~0.04 counts per minute for beta and alpha respectively (see Figures 9-1 and 9-2). Daily performance checks are done using calibration sources, ^{239}Pu for alpha and ^{90}Sr/^{90}Y for beta, for efficiency control charting (2σ warning and 3σ limits) and ensuring that alpha/beta cross-talk are within limits (≤ 0% α into beta and ≤ 0.1% beta into alpha). Sixty-minute background counts are also recorded daily (count must be within the mean background ±3σ) by counting an empty planchet. The self-absorption curve was obtained individually for alpha and beta and used for all sample counts. The mean counting efficiencies for the systems are found to be around 25% for alpha and 38% for beta (see Figures 9-3 and 9-4).

Sample Preparation for Radiochemical Analysis

After gross alpha/beta measurements, individual filters collected over a period of one week are combined into weekly composites. The weekly composite samples are used for the determination of actinide activities. Gamma analysis is performed concurrently on the same weekly composite. Only one half of the sample is used for the determination of the actinide activities. The remaining aliquot is archived.

Filter samples for radiochemical analysis are prepared by wet digestion with HNO_3, HCl and perchloric acid until the filter is totally dissolved. This mixture is heated to dryness and then re-dissolved in 20 mL of 1 M HCl. Generally, half of the sample is used for the determination of the actinide activities and other half for the gamma analysis. The actinides are concentrated in an iron hydroxide precipitate as $Fe(OH)_3$. After decantation and centrifugation, the precipitate is dissolved in 10 ml of conc. HNO_3 and diluted to 20 ml to make the solution 8 M in HNO_3. The oxidation state of plutonium as Pu(IV) was adjusted by adding 1 ml of 1 M NH_4I with a 10 min wait step, followed by 2 ml of 2 M $NaNO_2$. Plutonium is separated from americium and uranium using an anion exchange column. The fraction containing americium and uranium is separated using a TRU extraction chromatography column in 2 M HNO_3 as described in previous CEMRC reports (http://www.cemrc.org/report). The individual actinides are then micro-co-precipitated with a Nd-carrier and counted using

alpha spectrometry. The samples are counted for 5-days for alpha and 48 hours for gamma radionuclides as per CEMRC's standard counting protocol. A simplified scheme of the radiochemical separation process is shown in Figure 2-6.

Data Reporting

The activities of the actinides and gamma radionuclides in the WIPP underground air samples are reported in the following two ways: *activity concentration in* Bq/m^3 and *Activity density* (Bq/g). *Activity concentration* is calculated as the activity of radionuclides detected in Becquerel (Bq) divided by the volume of air in cubic meters (m^3). *Activity density* is calculated as the activity of radionuclides detected in Becquerel (Bq) divided by the aerosol mass collected on the filter in gram (g).

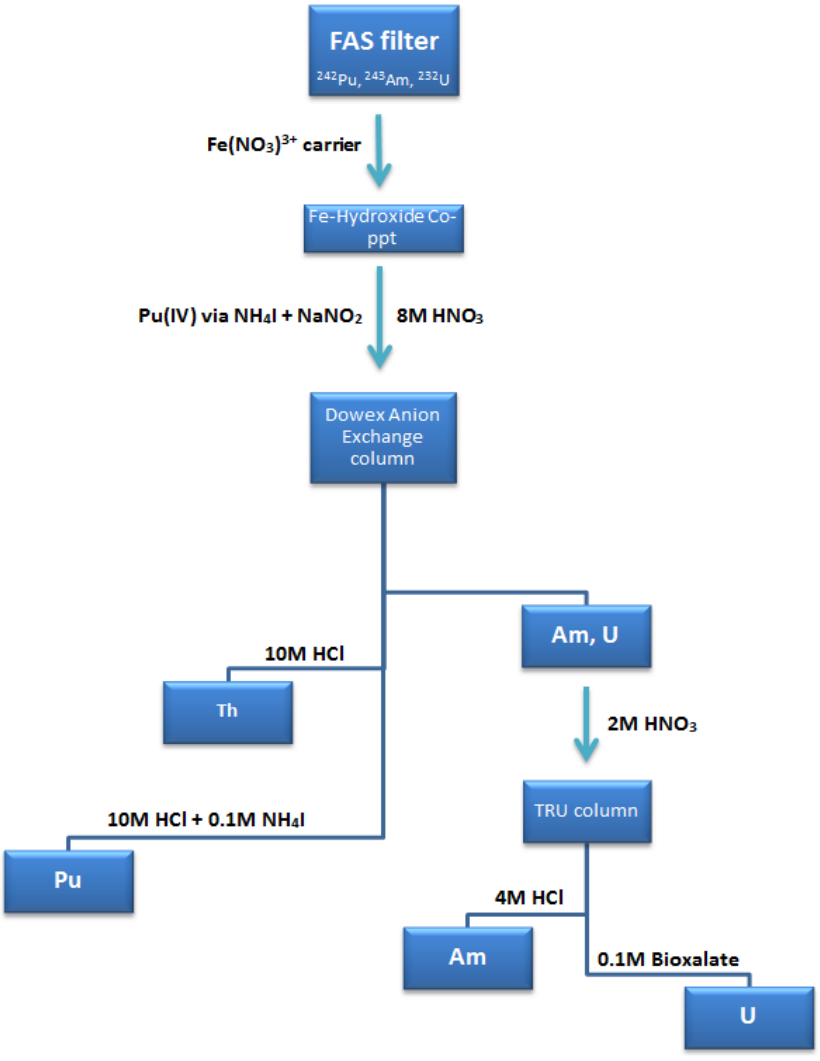


Figure 2-6: Flow Diagram Showing the Analysis of Stations A and B Filters

Results and Discussion

Gross Alpha and Beta concentrations in the WIPP underground Air (Station A, Pre-HEPA Filter)

The daily gross alpha and gross beta concentrations in the unfiltered underground air (air exhaust before the HEPA filtration or Station A) are shown in Figures 2-7 and 2-8. The gross alpha and beta activities appear to have gone back to the pre-release levels in 2015-2016. A small sporadic increase in gross alpha concentrations, shown on Figure 2-7, was attributable to the disturbance of entrained materials allowing them to be transported in the WIPP underground air due to ongoing investigative and clean-up efforts by underground personnel.

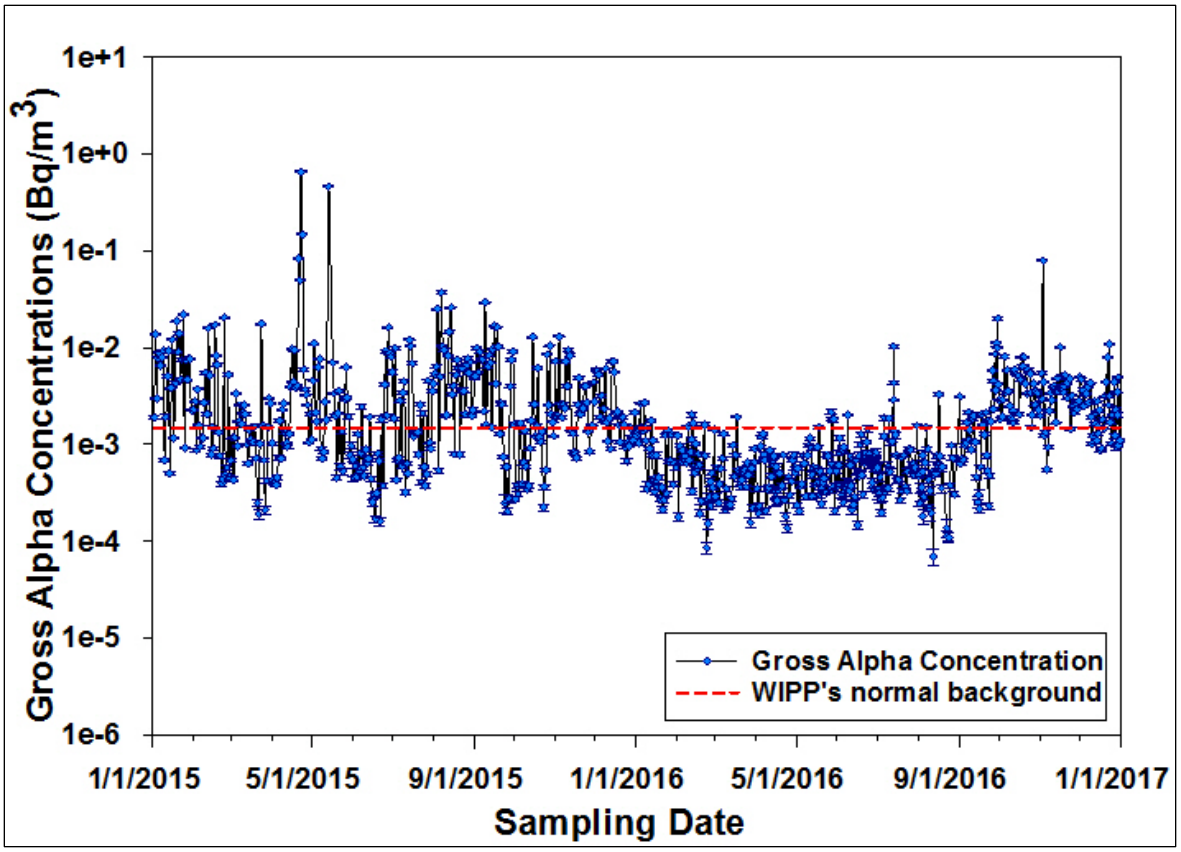


Figure 2-7: The Gross Alpha Concentrations in the WIPP Exhaust Air Before (Station A) HEPA during 2015-2016

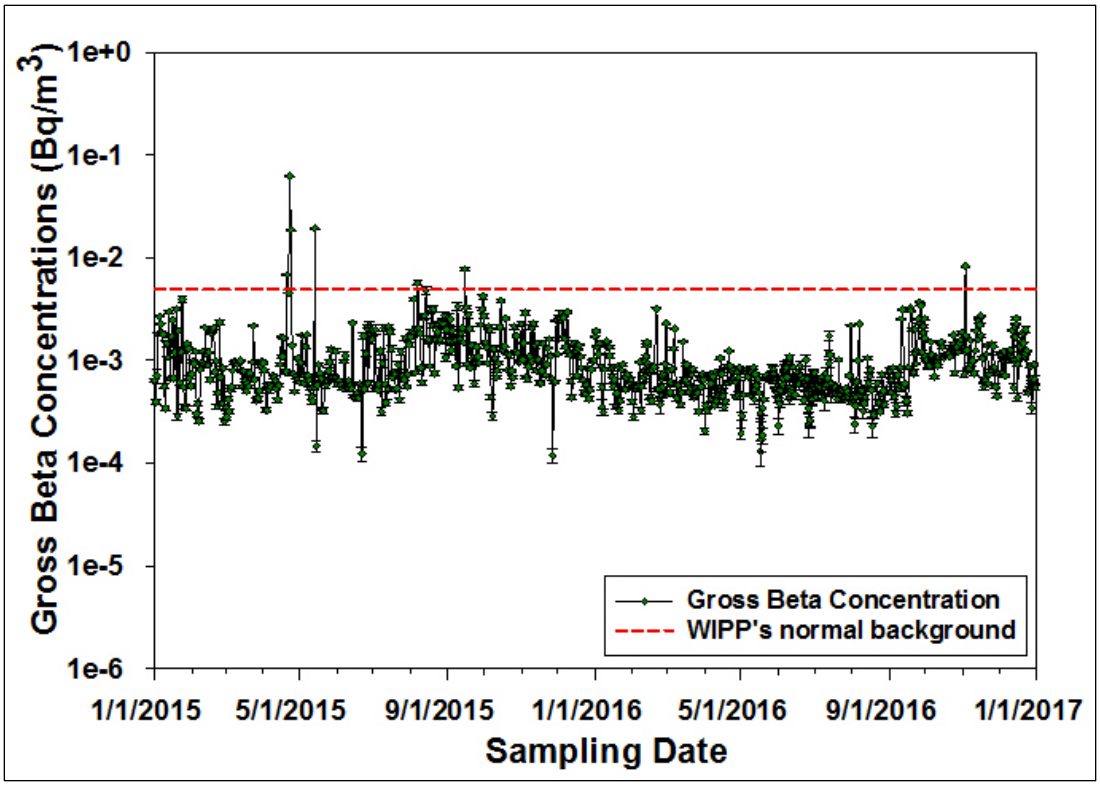


Figure 2-8: The Gross Beta Concentrations in the WIPP Exhaust Air Before (Station A) HEPA Filtration during 2015-2016

The pre- and post-release gross alpha and gross beta concentrations in the Station A filters are shown in Figures 2-9 and 2-10 for trend analysis purposes. There is no data for the period between February and June, 2014. This is because gross alpha and beta screening was not performed immediately following the February 14, 2014 underground radiation release event; instead, an emergency actinide separation campaign was carried out on individual or daily filters collected from Station A and Station B. However as radiation levels receded, the gross alpha and beta analysis resumed beginning March, 2014 for the Station A filters and beginning July, 2014 for the Station B filters.

The gross alpha and beta concentrations exhibit clear seasonal variability with peaks occurring in the winter. Prior to the February 14 radiological event, the pre-operational baseline data is compared with the operational data to assess the integrity of the WIPP project. The gross alpha and beta activity in air filters prior to arrival of waste at WIPP were used as a baseline concentration. The bulk of the activity in those samples results from naturally occurring radioactive materials, specifically radon daughters. The baseline concentrations of gross alpha and gross beta activities were 1.49 mBq/m^3 and 4.90 mBq/m^3, respectively. These data are then compared against disposal phase data to assess the radiological and ecological effects of radiation on workers and the general public that live and work around the WIPP. The minimum detectable activity concentrations and densities for the gross alpha emitters are ≈ 1 ×10-7 Bq/m^3 and ≈ 0.7 Bq/g, respectively, while for gross

beta emitters the corresponding values were ≈ 2 ×10-7 Bq/m^3 and ≈ 1.7 Bq/g. The reported gross alpha and beta activities are normalized by dividing the measured activities by the mass loadings on the sample filters or by the volume of air sampled. Therefore trends in the activity densities could either be due to changes in the amount of radioactivity in the sample or the aerosol mass in the samples as the volume of air sampled, which is not shown, has changed little during the course of the program and therefore, should have little or no effect on the activity concentrations.

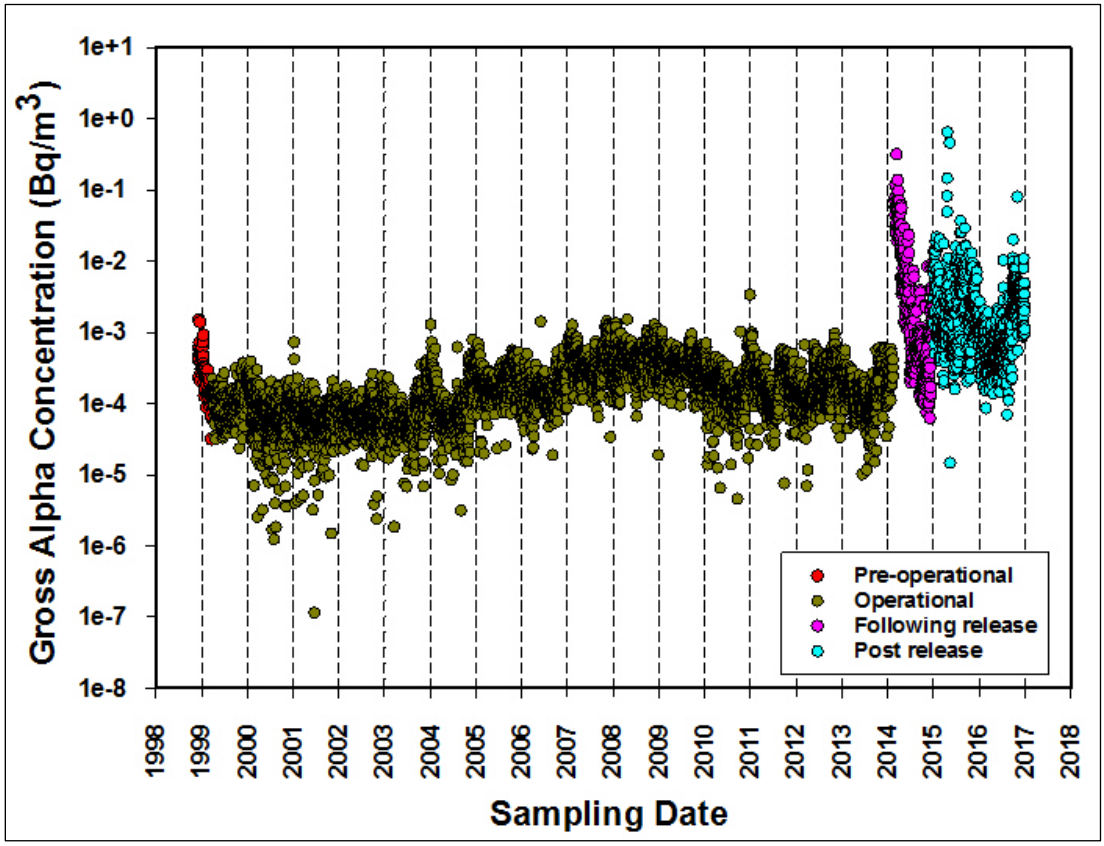


Figure 2-9: Pre- and Post-release Gross Alpha Concentration in Station A (Pre-HEPA) Filter

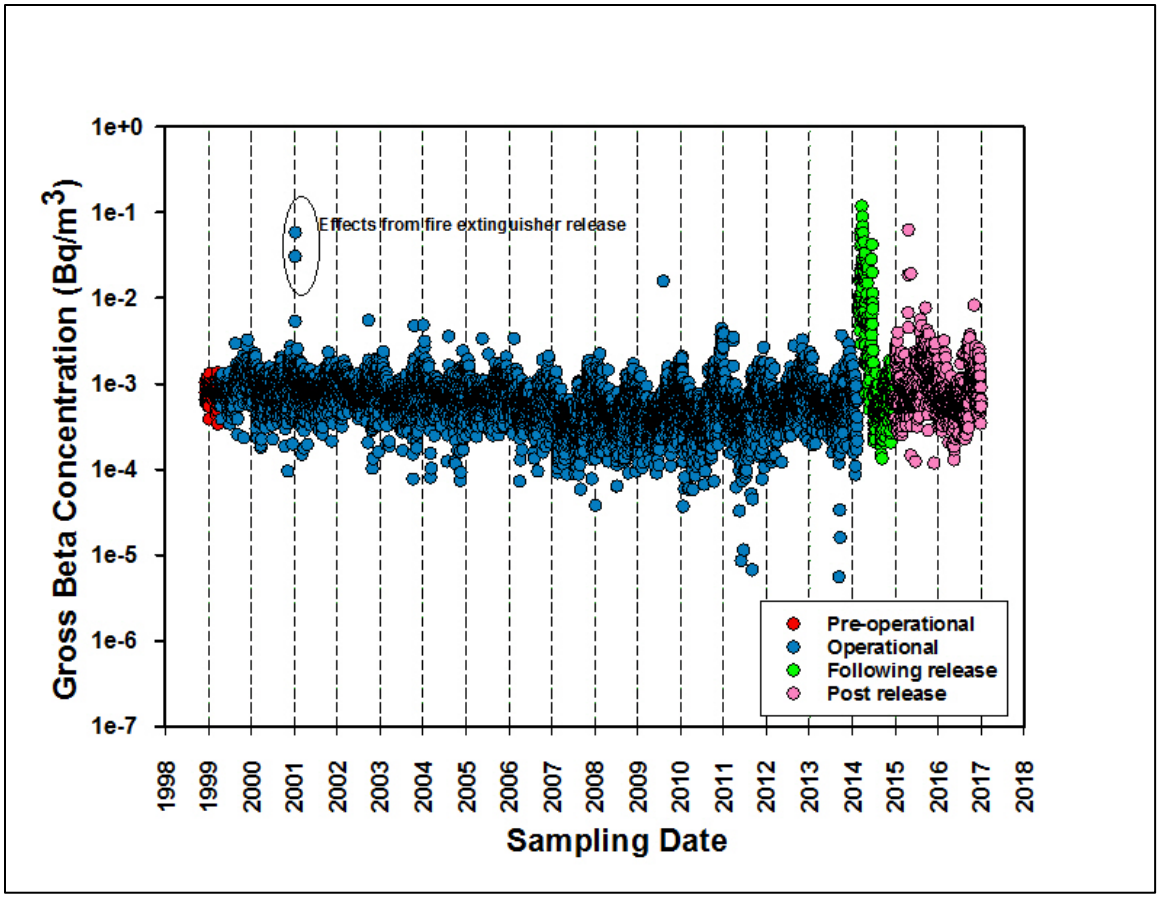


Figure 2-10: Pre- and Post-release Gross Beta Concentration in Station A (Pre-HEPA) Filter

Similar seasonal trends in gross beta data can also be seen (Figure 2-10). The two samples with elevated gross beta activity concentrations ca. 0.058 Bq/m3 observed in early 2001 (Figure 2-10) are because of contamination released from an underground fire extinguisher. Follow-up measurements verified that the fire retardant containing ^{40}K was the cause of the elevated results and that WIPP waste had not been released.

A time series plot of the gross alpha and gross beta densities (Bq/g) are shown in Figures 2-11 and 2-12. The current levels are within the range of our normal background for this particular Station. Since no gravimetric data was collected from the Station A filters following the radiation release event, no data are available for the period between February and July; 2014. The CEMRC resumed collecting gravimetric data beginning August, 2014.

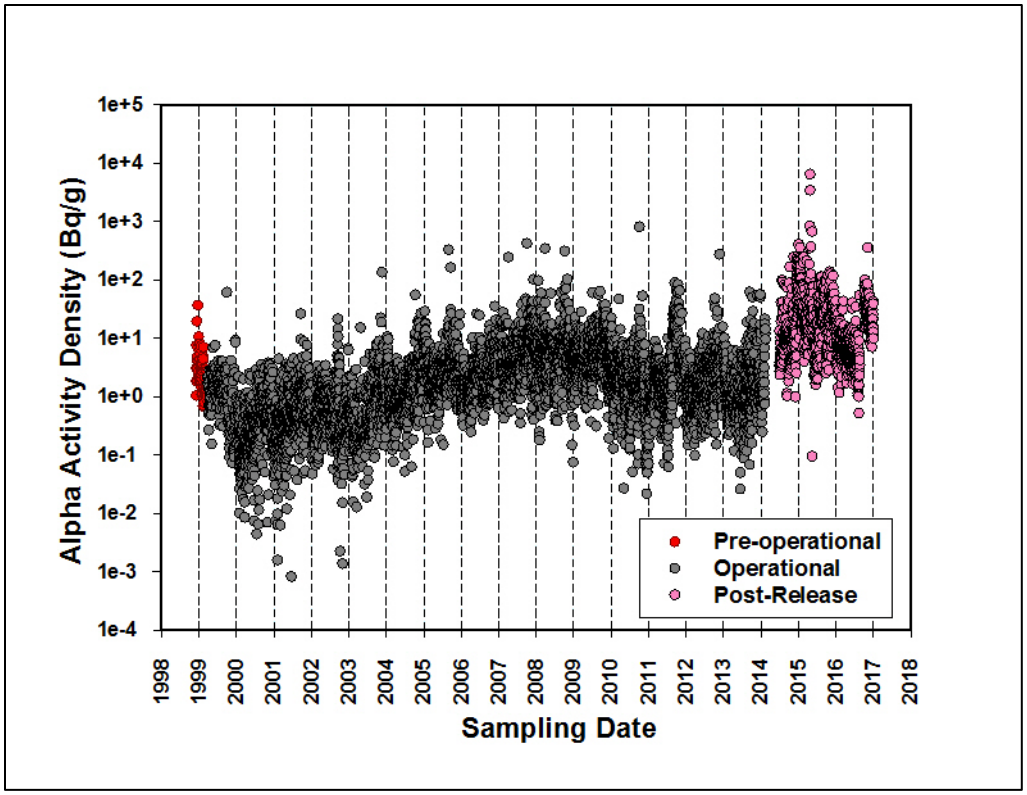


Figure 2-11: Gross Alpha Activity Densities Measured in Station A Filters

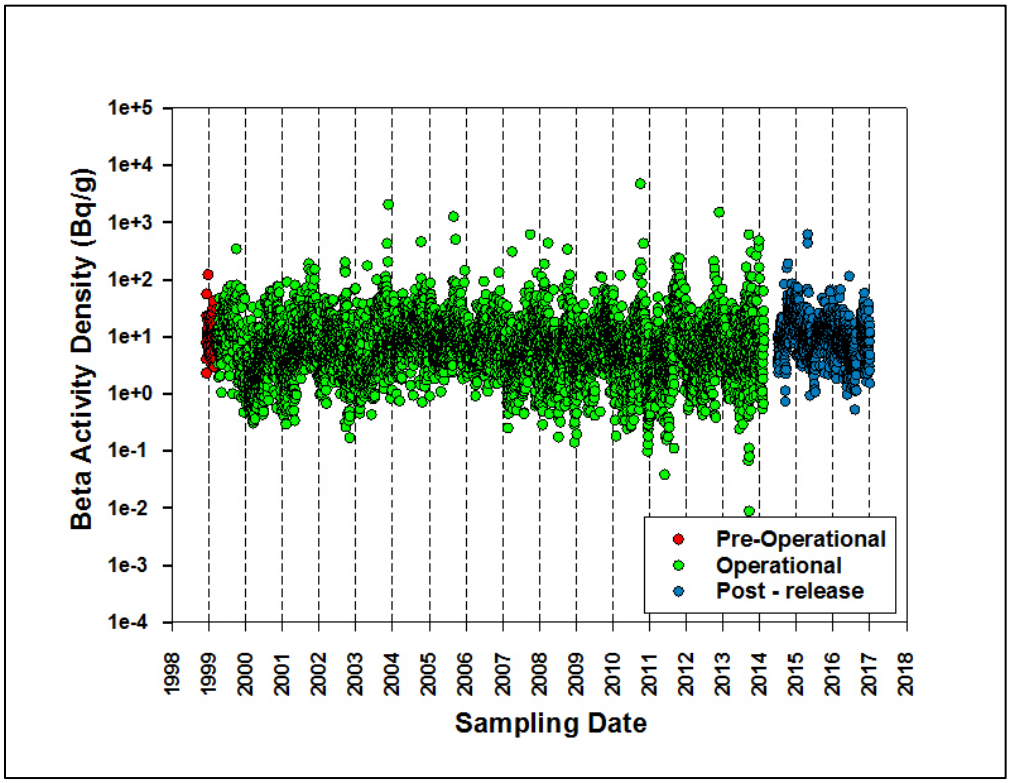


Figure 2-12: Gross Beta Activity Densities Measured in Station A Filters

Actinide Concentrations in the WIPP's Unfiltered Underground Air (Pre-HEPA, Station A) in 2016

The time series of the activity concentrations of transuranic radionuclides $^{239+240}$Pu and ^{241}Am measured at Station A (Pre- HEPA filtration) since the February 2014 underground radiation release event are shown in Figure 2-13. As anticipated, the values detected at Station A immediately after the underground radiation release event were considerably higher than those historically measured for this Station. The maximum air concentrations of americium and plutonium detected at Station A were 4337 Bq/m^3 for ^{241}Am, 672 Bq/m^3 for $^{239+240}$Pu and 30.3 Bq/m^3 for ^{238}Pu. These results were measured on February 15, 2014. By the morning of February 21, 2014, these levels had dropped to about 0.65 Bq/m^3 for ^{241}Am and 0.06 Bq/m^3 for $^{239+240}$Pu. It is important to note that these high activity values are reflective of what was detected in the unfiltered underground air prior to going through HEPA filtration systems and do not represent the activity levels that ultimately escaped to the environment.

As the levels of ^{241}Am and $^{239+240}$Pu in the WIPP exhaust air prior to HEPA filtration continued to decrease, as measured by the Station A sampling skid, a weekly composite filter sample has been used for the determination of actinides since April 22, 2014 from the Station A location. The weekly composite filter samples results from Station A are summarized in Tables 2-1 through 2-3. As can be seen, trace amounts of ^{241}Am and $^{239+240}$Pu continue to be measurable above MDC (minimum detectable concentration) in these filters; however, current levels are very low and are not expected to cause any adverse health or environmental consequences. The weekly activity concentrations of ^{241}Am, $^{239+240}$Pu and ^{238}Pu measured at filter samples collected from Station A since April 2014 is shown in Figure 2-14. Although the values measured were above the pre-release background levels, it is important to note that the levels detected were very low and well below any level of public health or environmental concern. There is no risk to anyone from contamination levels this low. Additionally, it is relevant to emphasize that the levels reported were only detectable because of the ultra-sensitivity of modern radiation monitoring equipment and radiochemical analyses methods performed.

The activity density data immediately following the radiation release event were not available as filters collected during that period were not weighed. However, the aerosol mass data collected since July 2014 showed that the activity density remained fairly consistent through December 2016. The $^{239+240}$Pu activity density (activity per unit mass aerosol collected) at Station A was in the range of 0.16-8.22 Bq/g, while that of ^{241}Am was in the range of 1.04-77.1 Bq/g. The weekly activity density of ^{241}Am, $^{239+240}$Pu and ^{238}Pu at Station A are shown in Figure 2-15 and the individual values are listed in Tables 2-4 through 2-6.

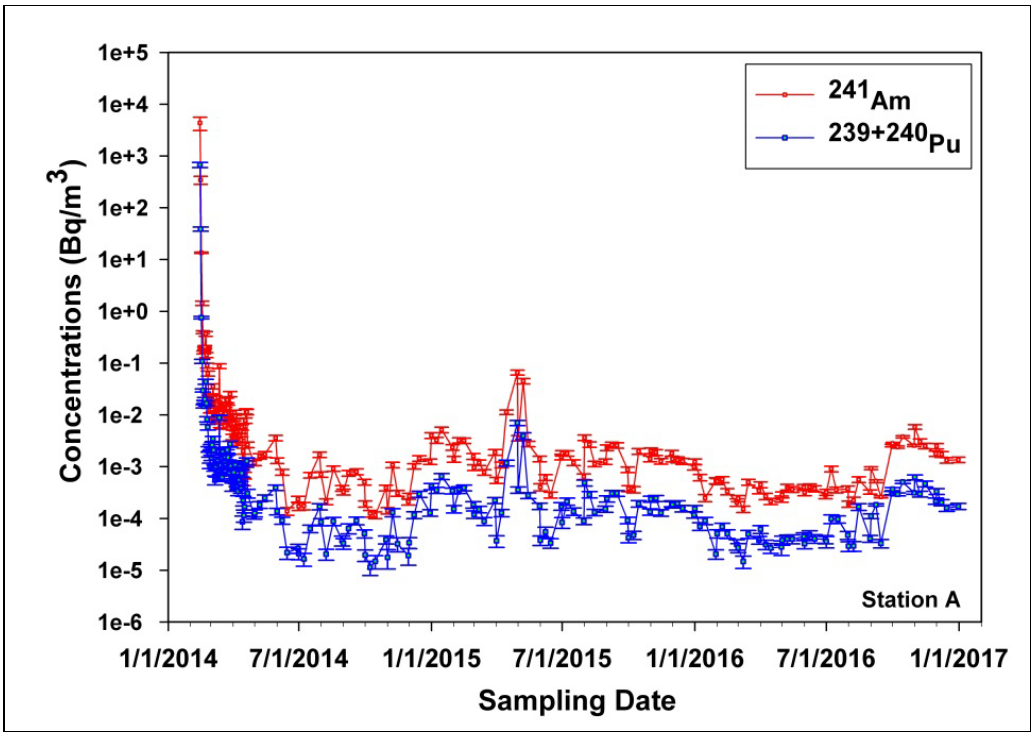


Figure 2-13: Times Series of ^{241}Am and $^{239+240}$Pu Concentrations in Station A (Pre-HEPA) filters for the Period 2014-2016

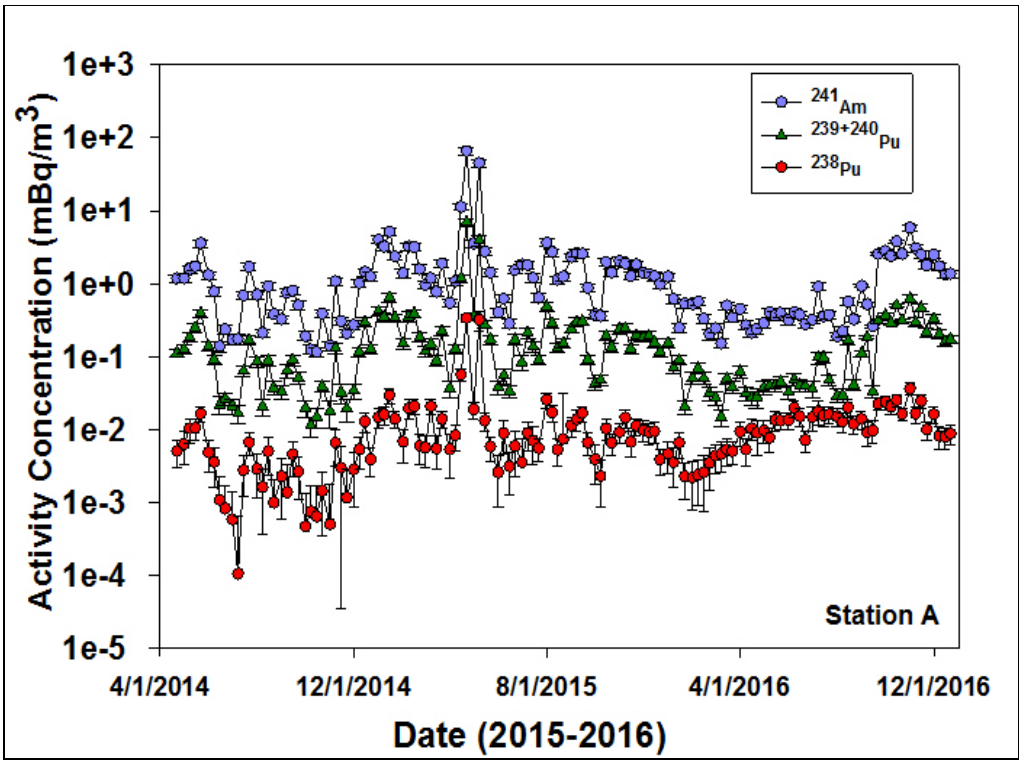


Figure 2-14: The Weekly ^{241}Am, $^{239+240}$Pu and ^{238}Pu Concentrations in Station A (Pre-HEPA) filters during 2016

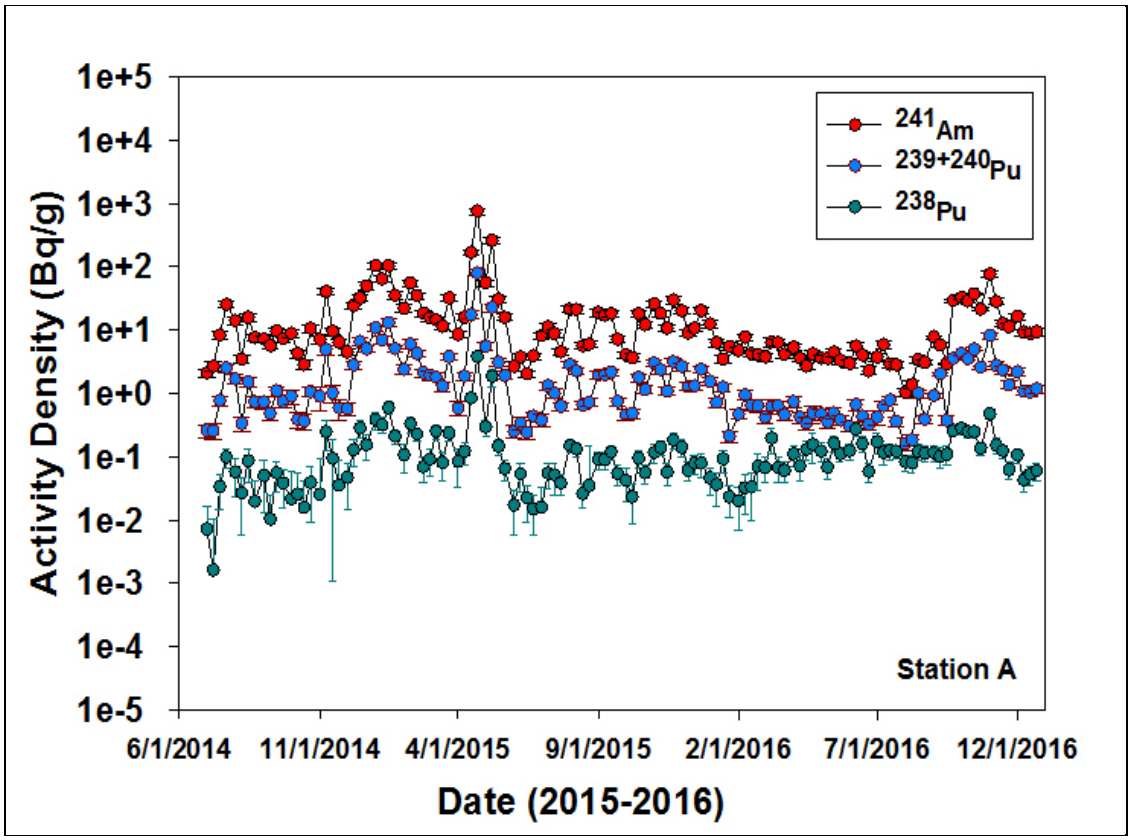


Figure 2-15: The Weekly ^{241}Am, $^{239+240}$Pu and ^{238}Pu Activity Density in Station A (Pre-HEPA) filters during 2016

Gross Alpha and Beta concentrations in the WIPP underground Air (Station B, Post-HEPA Filter)

In order to determine the amount and type of radionuclides that were ultimately released into the environment, an analysis of Station B filters was performed as these filters sampled the underground exhaust air after HEPA filtration. The daily gross alpha and gross beta concentrations in the WIPP underground air after HEPA filtration (Station B) are shown in Figure 2-16. It is important to note that the CEMRC has been performing gross alpha and gross beta analyses on Station B filters since July 2014. Filter samples collected prior to July 2014 were not counted for gross alpha and gross beta and instead, an emergency actinide separation campaign was carried out on individual or daily filters collected from Station B in order to provide isotopic results to interested parties as quickly as possible. The pre-operational gross alpha and gross beta concentration values measured at Station A were used as a baseline concentration for the filter samples collected from Station B as the CEMRC had not routinely conducted gross alpha/beta analyses on Station B filters prior to the February 14, 2014 underground radiation release event. As would be expected, the Station B analyses showed much lower levels of activity as compared to those of Station A.

A spike in gross alpha activity during the third week of October 2014 is attributed to the restart of the 860A fan on October 21, 2014. The 860A fan was initially started on February 14, 2014, when continuous air monitors (CAM) in the WIPP underground facility detected elevated levels of radioactive contamination and shifted the underground ventilation system into filtration mode, forcing all air exiting the facility through the HEPA filtration system. Naturally, due to remaining contamination in the exhaust drift of the repository, the WIPP underground facility has remained in filtration mode since the event occurred. The 860A fan ran for approximately two months following the February 2014 underground radiological incident before being taken off-line for maintenance-related activities. Since that time, the 860B or the 860C fans have been operating to continue the air filtration process. Because the 860A fan was operational immediately following the radiological release, it is expected that a small amount of residual contamination could be present in the adjacent ductwork and the interior workings of the fan which could result in a low level of contamination being released during the restart. As can be seen in Figure 2.16, the current gross alpha and beta activities at Station B have returned to normal background levels.

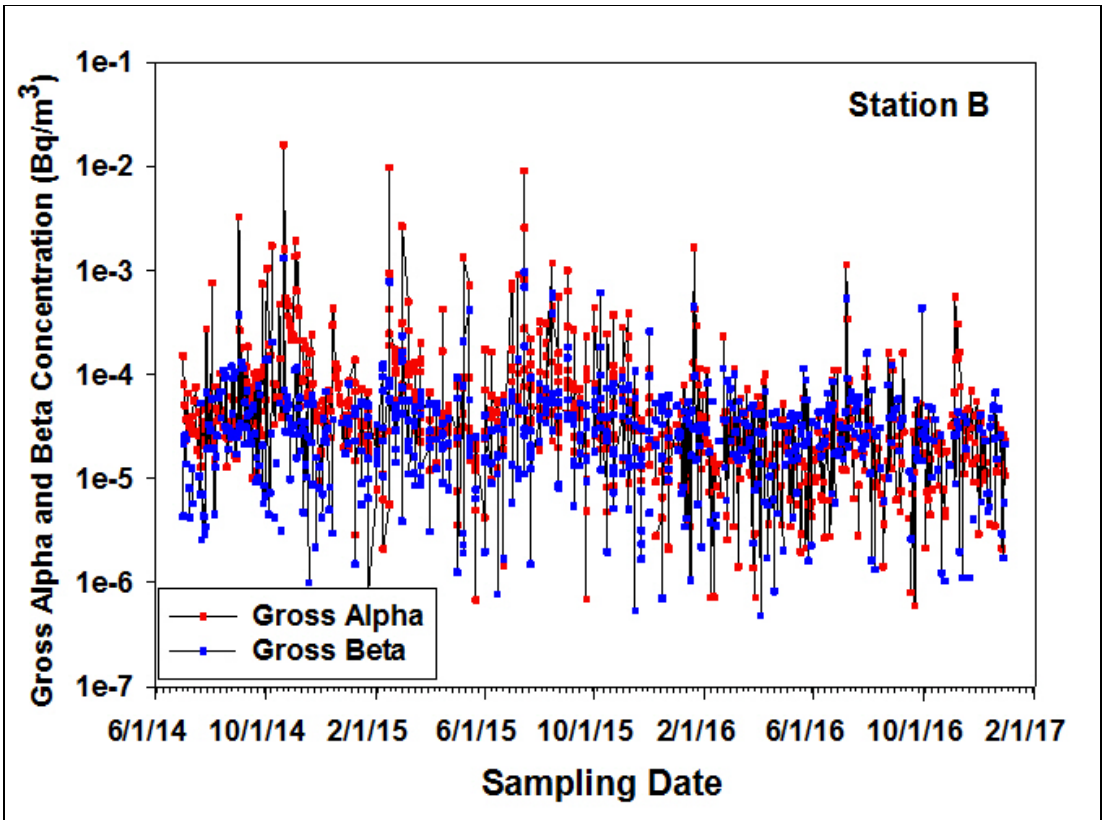


Figure 2-16: Daily Gross Alpha and Gross Beta Activity in the Filtered Underground Air (Station B) during 2014-2016

Actinide concentrations in the WIPP underground Air (Station B, Post-HEPA filter) in 2016

Sampling results from Station B (WIPP exhaust air released to the environment after filtration) showed much lower levels, about 2.3 Bq/m^3 of air for ^{241}Am and 0.22 Bq/m^3 of air for $^{239+240}$Pu when it was collected on February 18, 2014 at the first collection opportunity, four days after the underground radiation release event occurred. Given that this particular filter remained in the sampler from the time of the underground radiation detection event until four days after the event, this filter was representative of the total amount of ^{241}Am and $^{239+240}$Pu, and ^{238}Pu that may have been released into the environment. By February 21, 2014, a Station B sample had only about 0.43 Bq/m^3 of combined Pu and Am activity. By the middle of April 2014, the concentrations of ^{241}Am and $^{239+240}$Pu measured at Station B were in the range 0.11 to 0.53 Bq/m^3 and 0.01 to 0.06 Bq/m^3 respectively. The ^{238}Pu level has been below the detection limit in samples from February 19, 2015 to the present. The time series of the activity concentrations of transuranic radionuclides $^{239+240}$Pu and ^{241}Am measured at Station B (Post-HEPA filtration) since the release-event are shown in Figure 2-17. As the concentration levels of these radionuclides receded, beginning April 22, 2014, actinide analyses have been performed on weekly composite samples. The weekly actinide analyses of Station B filters were continued until December 2015 and then beginning January 2016, monthly composite samples have been used for the actinides analyses. The activity concentrations of ^{241}Am and $^{239+240}$Pu in the daily/weekly/monthly filters collected from Station B since April 2014 are shown in Figure 2-18. The monthly composite filter results from Station B measured during 2016 are summarized in Tables 2-7 through 2-9.

CEMRC began collecting aerosol mass data of Station B filters beginning August of 2014. The $^{239+240}$Pu activity density (activity per unit mass aerosol collected) at Station B was in the range 0.051-1.05 Bq/g, while that of ^{241}Am was in the range of 0.41-9.59 Bq/g. The weekly activity density of ^{241}Am and $^{239+240}$Pu at Station B are shown in Figure 2-19 and the individual values are summarized in Tables 2-10 through 2-12.

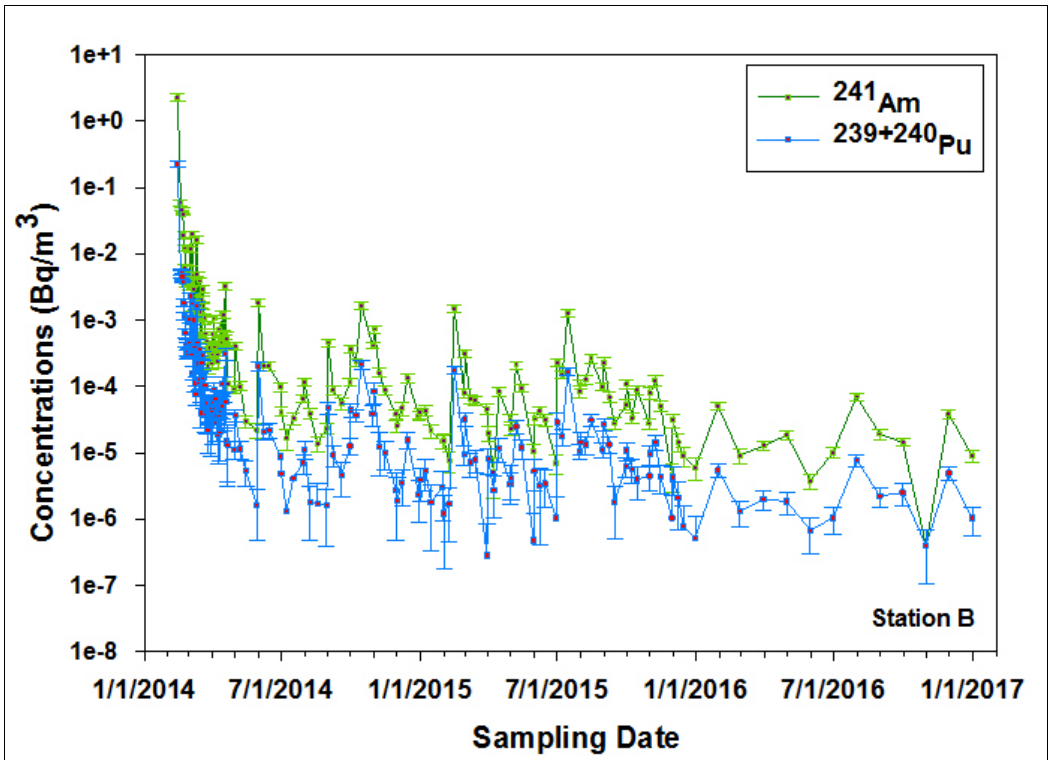


Figure 2-17: Times Series of ^{241}Am and $^{239+240}$Pu Concentrations in Station B (Post-HEPA) during 2014-2016

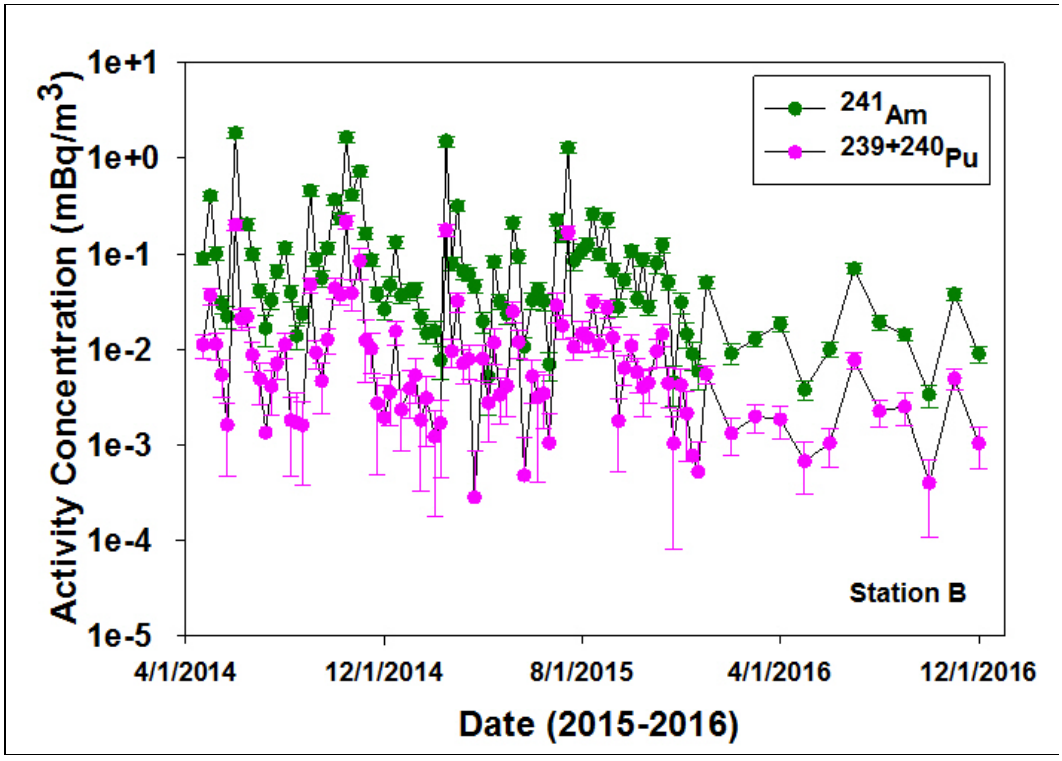


Figure 2-18: The Weekly ^{241}Am and $^{239+240}$Pu Concentrations in Station B (Post-HEPA) filters 2014-2016

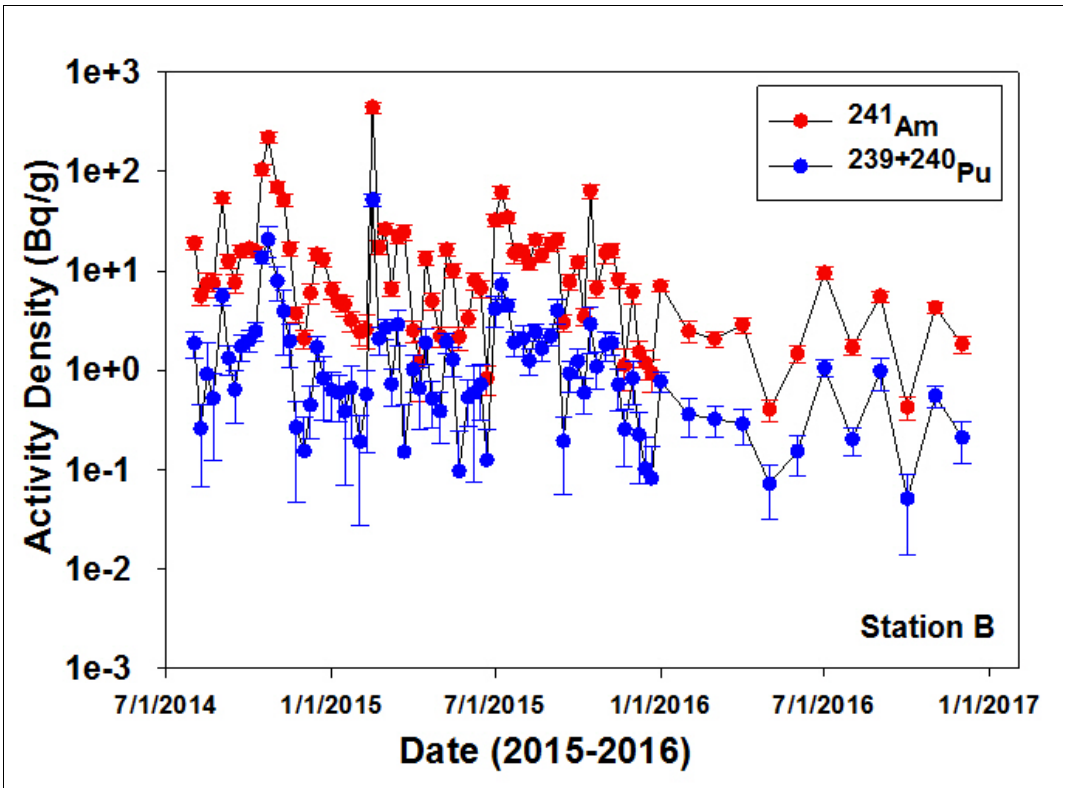


Figure 2-19: The Weekly ^{241}Am and $^{239+240}$Pu Activity density in Station B (Post-HEPA) filters 2014-2016

An analysis of historical operational data indicates occasional detections of trace amounts of $^{239+240}$Pu, ^{238}Pu, and ^{241}Am in the exhaust air released from the WIPP over time (Figure 2-20). From 2000 through 2013, only nine Station A measurements can be declared as containing a certain detection of a radionuclide. Detectable concentrations of Pu isotopes ($^{239+240}$Pu, or ^{238}Pu) and ^{241}Am only occurred in four monthly composite samples from 2003, 2008, 2009 and 2010 (CEMRC Report 2011). As ^{238}Pu concentrations were above detection limits in two of the monthly composite samples (February 2008 and April 2009), these two composite samples were used to calculate the activity ratios between ^{238}Pu and $^{239+240}$Pu. The February 2008 sample ratio was 0.039 and the April 2009 sample ratio was 0.023. A mean ^{238}Pu /$^{239+240}$Pu activity ratio of 0.025±0.004 (0.019-0.039) is compatible with a global fallout origin as reported in different studies (Kelly et al., 1999, Hardy et al., 1973). This compatibility is not proof that there was not a trace of ^{238}Pu released from within the repository; it is only suggestive of a global fallout origin. It is important to note that activities detected in those four composites were extremely low and did not even trigger the underground Continuous Air Monitors (CAM) that are used to detect any release of radioactivity. Based on an extensive analyses of this data the CEMRC concludes that there has been no unambiguous evidence of releases from WIPP operations prior to the February 14, 2014 underground radiation release event.

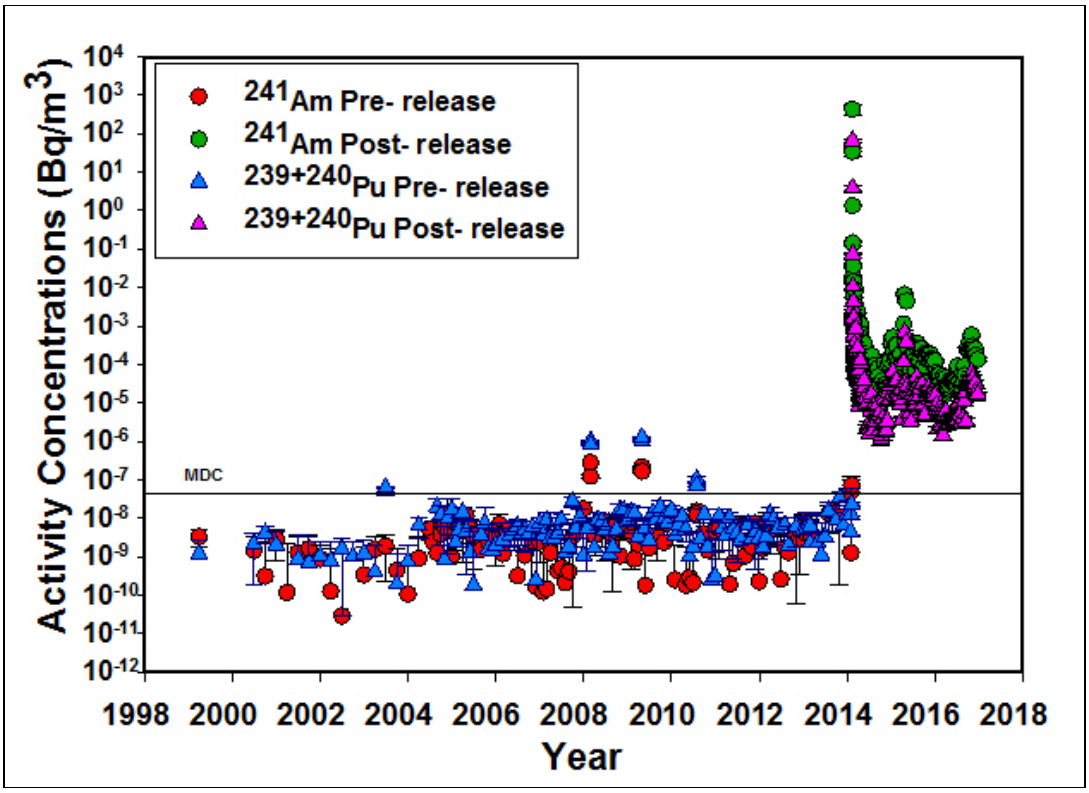


Figure 2-20: Pre- and Post-radiological Event of $^{239+240}$Pu and ^{241}Am Concentrations in the WIPP Exhaust Air at Station A (Pre-HEPA)

Uranium concentrations in the WIPP underground Air (Station A and Station B)

The naturally occurring isotopes of uranium were detected in some monthly composites samples collected from Station A and Station B in 2016. Uranium is naturally occurring radionuclides found in the environment. Thus, the detection of uranium in the WIPP underground air is normal. The highest concentrations detected were 1.21E-6 Bq/m^3 for ^{234}U and 6.10E-7 Bq/m^3 for ^{238}U at Station A and 5.0E-6 Bq/m^3 for ^{234}U and 3.58E-7 Bq/m^3 for ^{238}U at Station B. The ^{235}U slightly above the MDC was detected in three monthly composites samples from Station A and one monthly composite sample from Station B. The individual concentrations and densities values measured are summarized in Tables 2-17 and 2-18 (Station A) and Tables 2-19 and 2-20 (Station B).

Where detected, the ^{234}U results were similar to those of ^{238}U for activity concentration and density, indicating secular equilibrium between the two isotopes. These results are consistent with those reported in previous CEMRC, reports. The concentrations of uranium isotopes measured in Station A and Station B filter samples are shown in Figures 2-21 through 2-24.

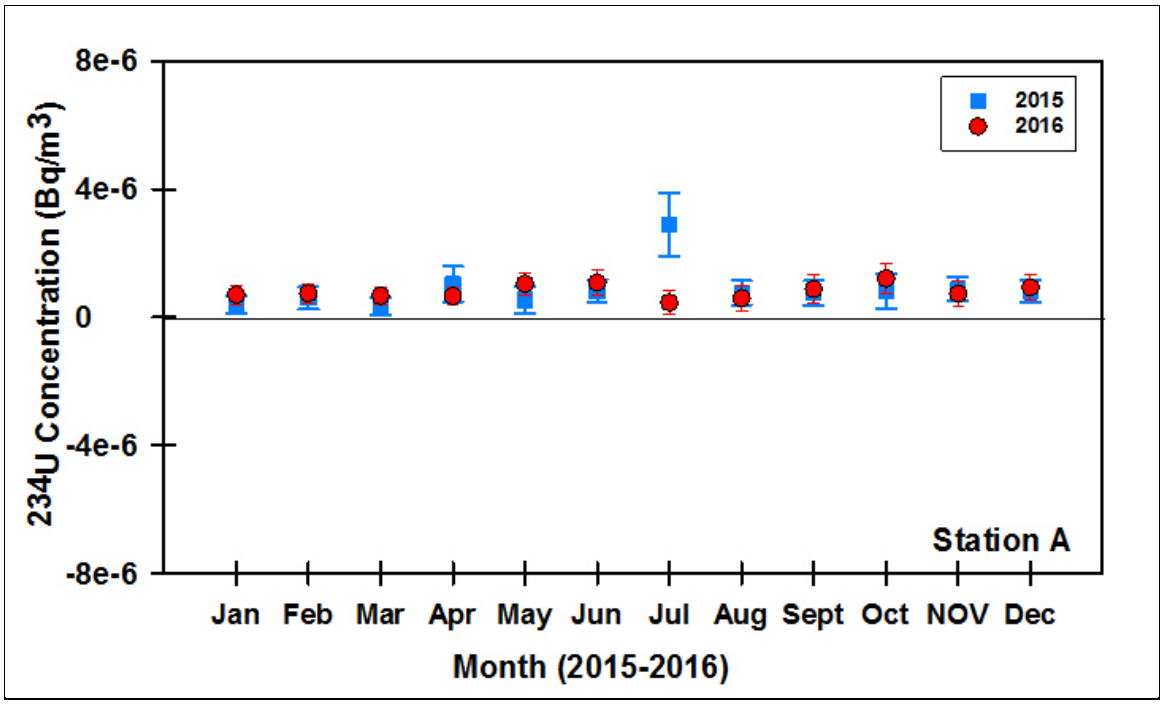


Figure 2-21: The ^{234}U Concentrations in the WIPP Exhaust air at Station A (Pre-HEPA) in 2015-2016

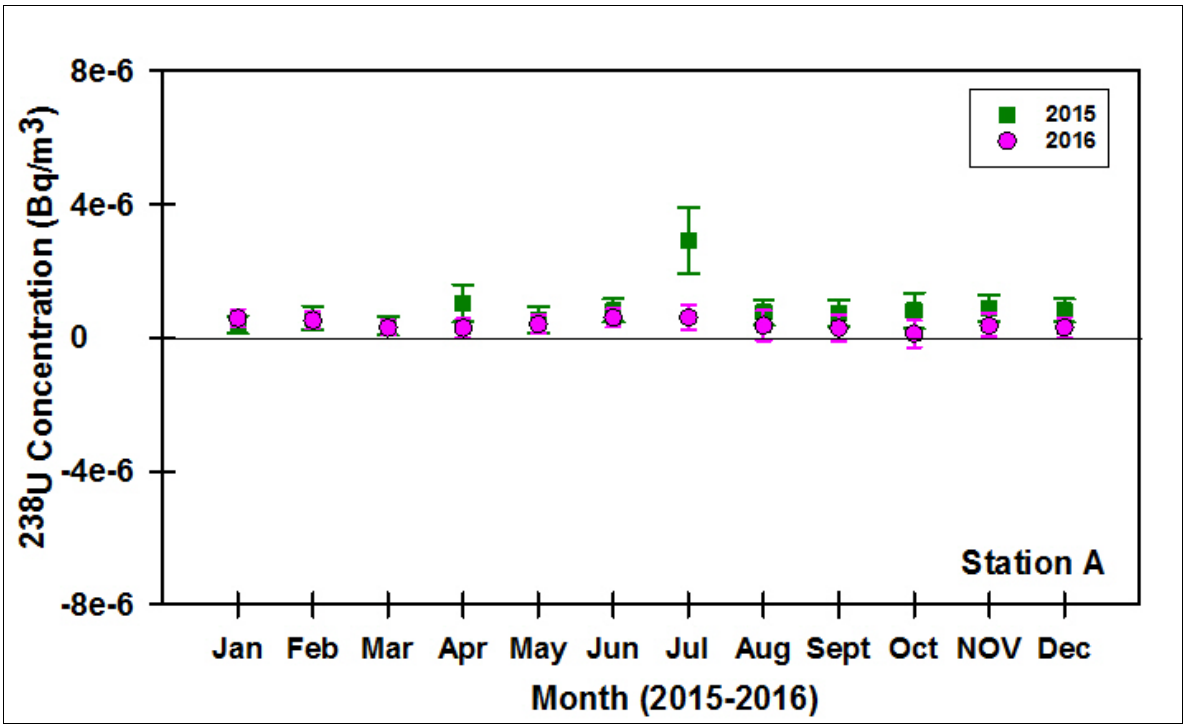


Figure 2-22: The ^{238}U Concentrations in the WIPP Exhaust air at Station A (Pre-HEPA) in 2015-2016

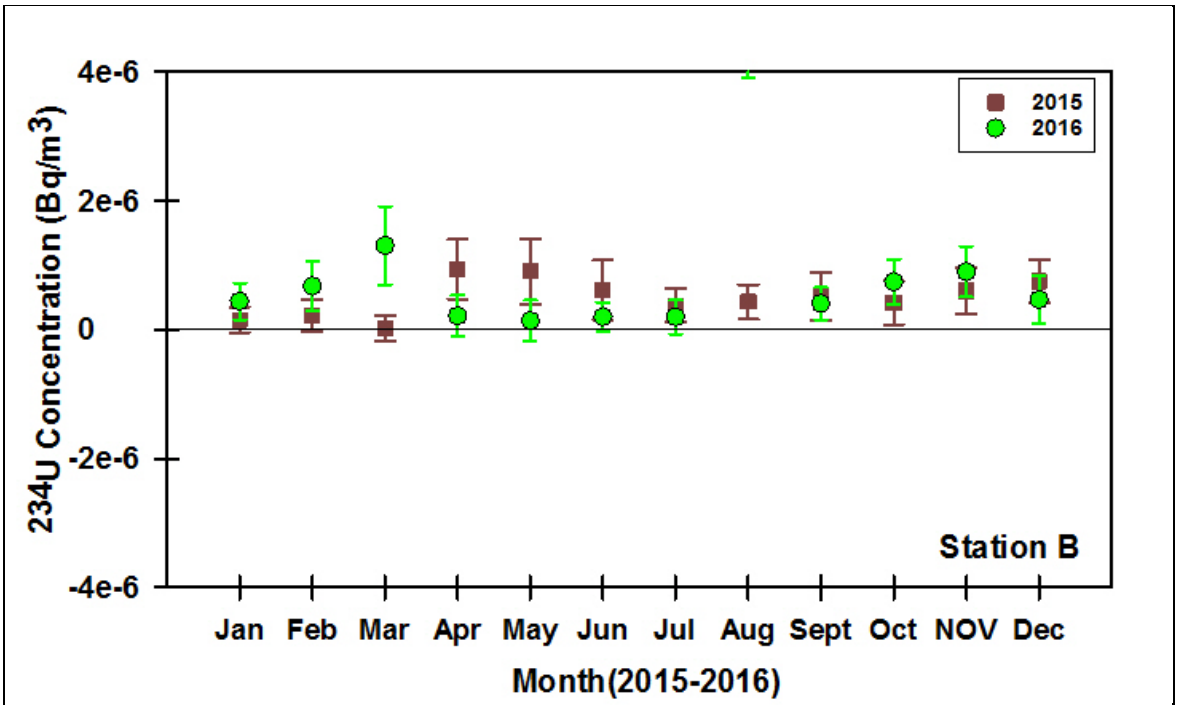


Figure 2-23: The ^{234}U Concentrations in the WIPP Exhaust air at Station B (Post-HEPA) in 2015-2016

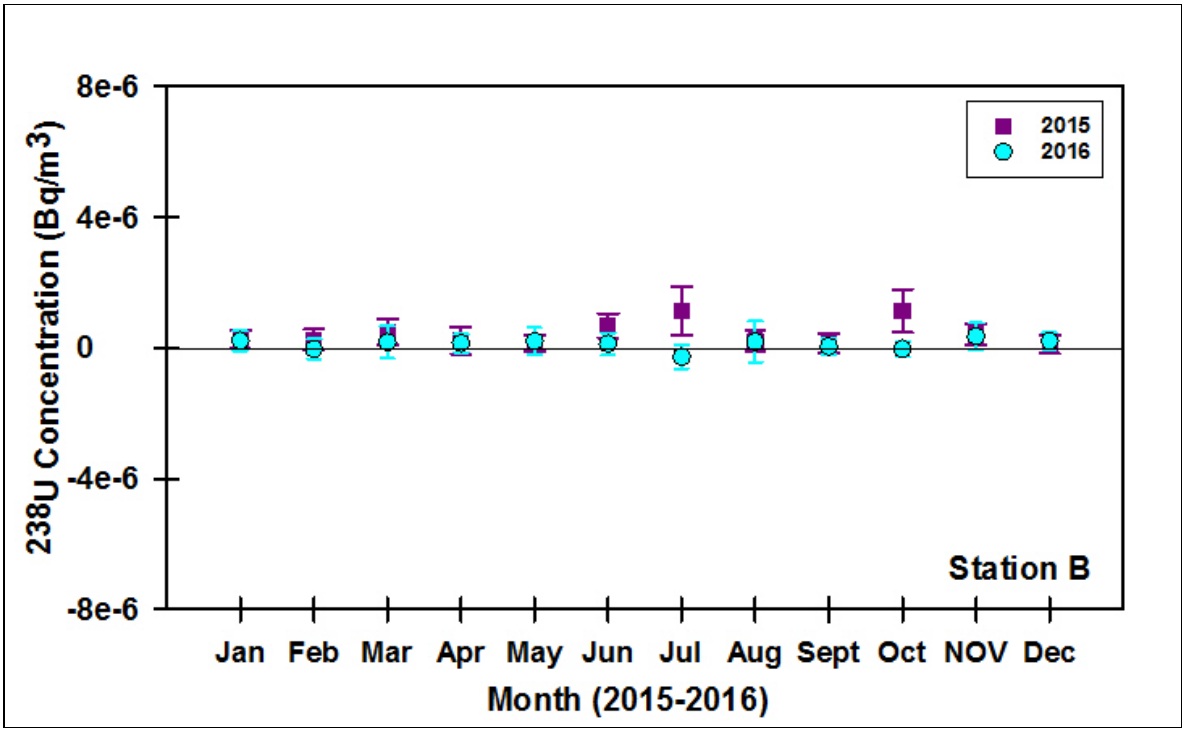


Figure 2-24: The ^{238}U Concentrations in the WIPP Exhaust air at Station B (Post-HEPA) in 2015-2016

Gamma radionuclide concentrations in the WIPP underground Air (Station A and Station B)

No detectable gamma-emitting radionuclides were observed in any of the filter samples collected from Station A or Station B in 2016. An analysis of historical operational data indicates detection of ^{137}Cs only once in a Station A filter collected on February 14, 2014, immediately following the underground radiation release event at the WIPP. The concentrations of gamma-emitters ^{137}Cs, ^{60}Co and ^{40}K measured in Station A and Station B filter samples are shown in Figures 2-25 through 2-30. The individual values measured are summarized in Tables 2-21 through 2-23 (Station A) and Tables 2-24 through 2-26 (Station B).

An analysis of historical operational data indicates that with the exception of occasional detections from ^{40}K no detectable gamma-emitting radionuclides were observed during the last fifteen years of monitoring. Since these isotopes were not detected, no comparison between years or among locations was performed.

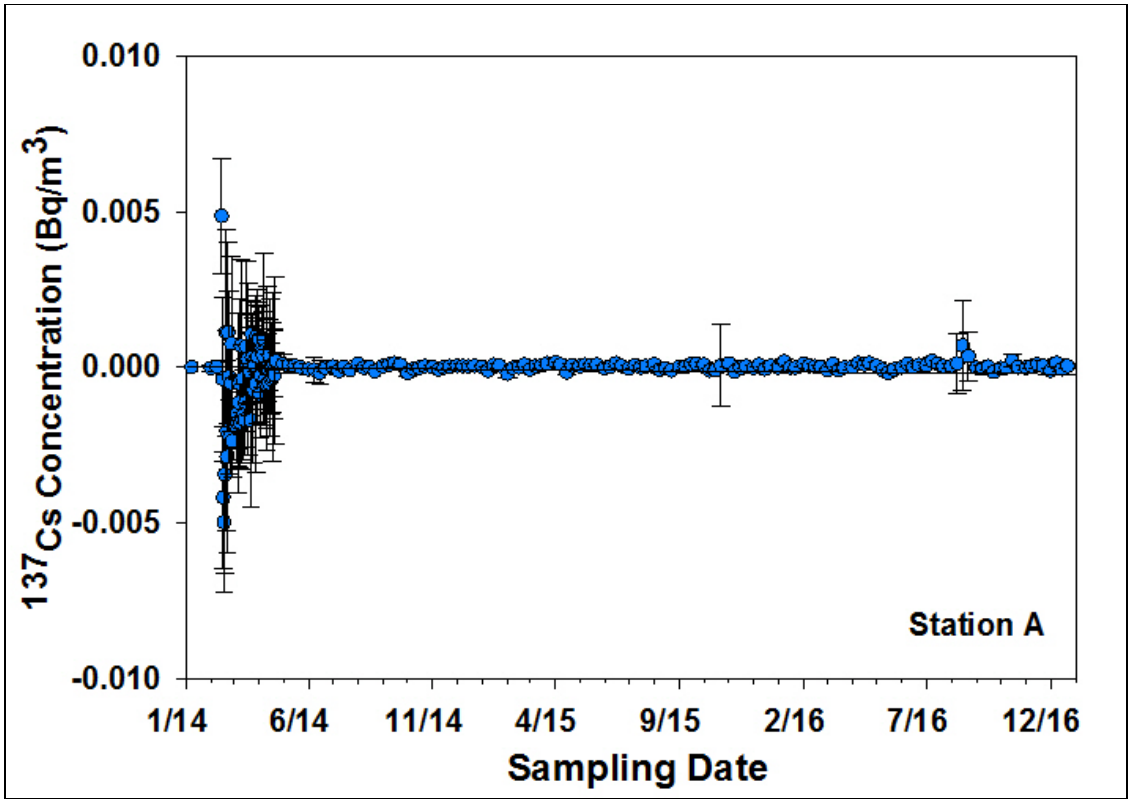


Figure 2-25: The ^{137}Cs Concentrations in the WIPP exhaust air at Station A (Pre-HEPA)

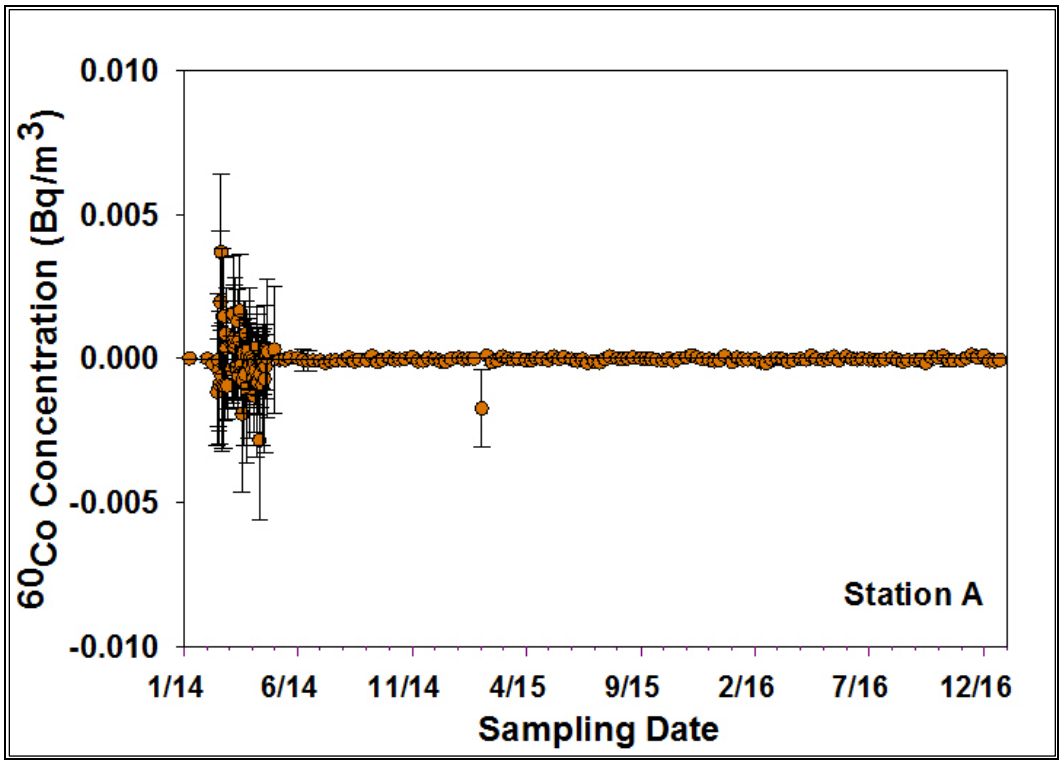


Figure 2-26: The ^{60}Co Concentrations in the WIPP exhaust air at Station A (Pre-HEPA)

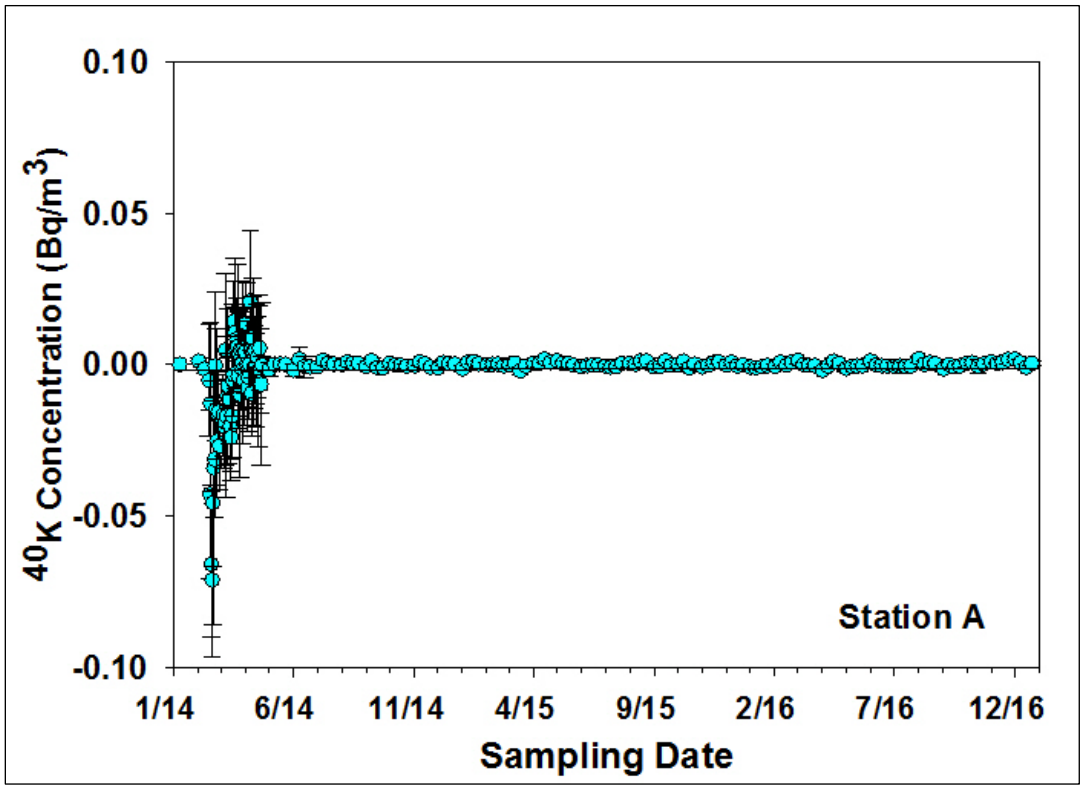


Figure 2-27: The ^{40}K Concentrations in the WIPP exhaust air at Station A (Pre-HEPA)

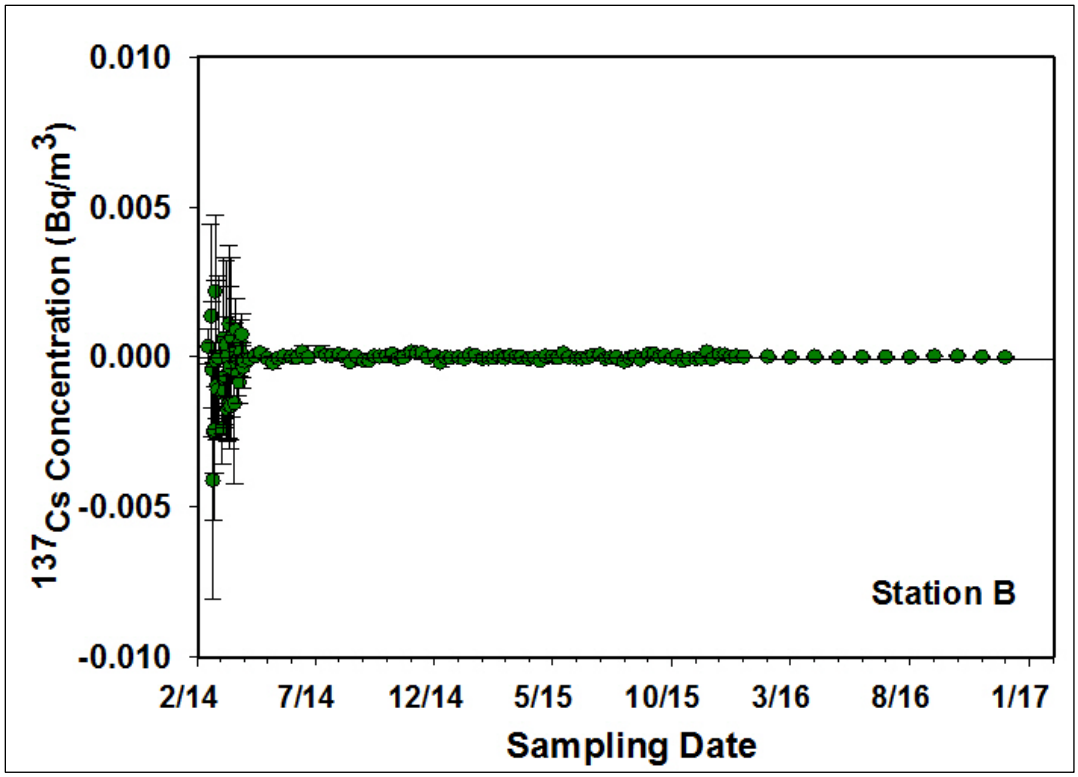


Figure 2-28: The ^{137}Cs Concentrations in the WIPP exhaust air at Station B (Post-HEPA)

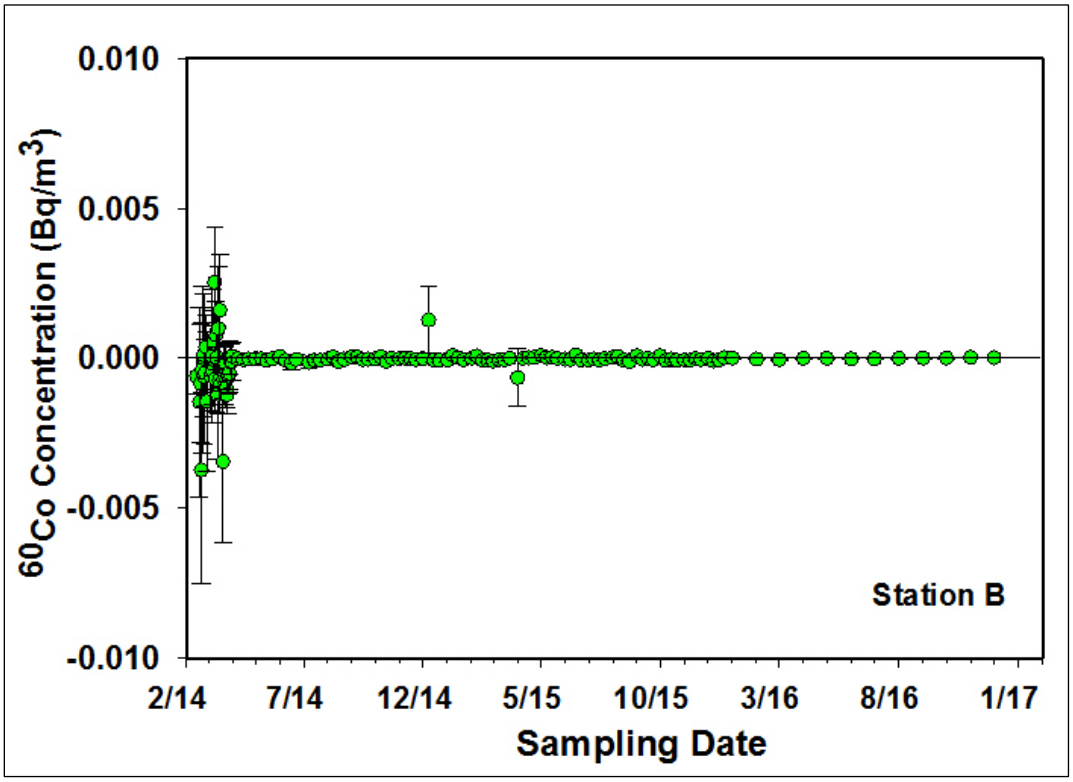


Figure 2-29: The ^{60}Co Concentrations in the WIPP exhaust air at Station B (Post-HEPA)

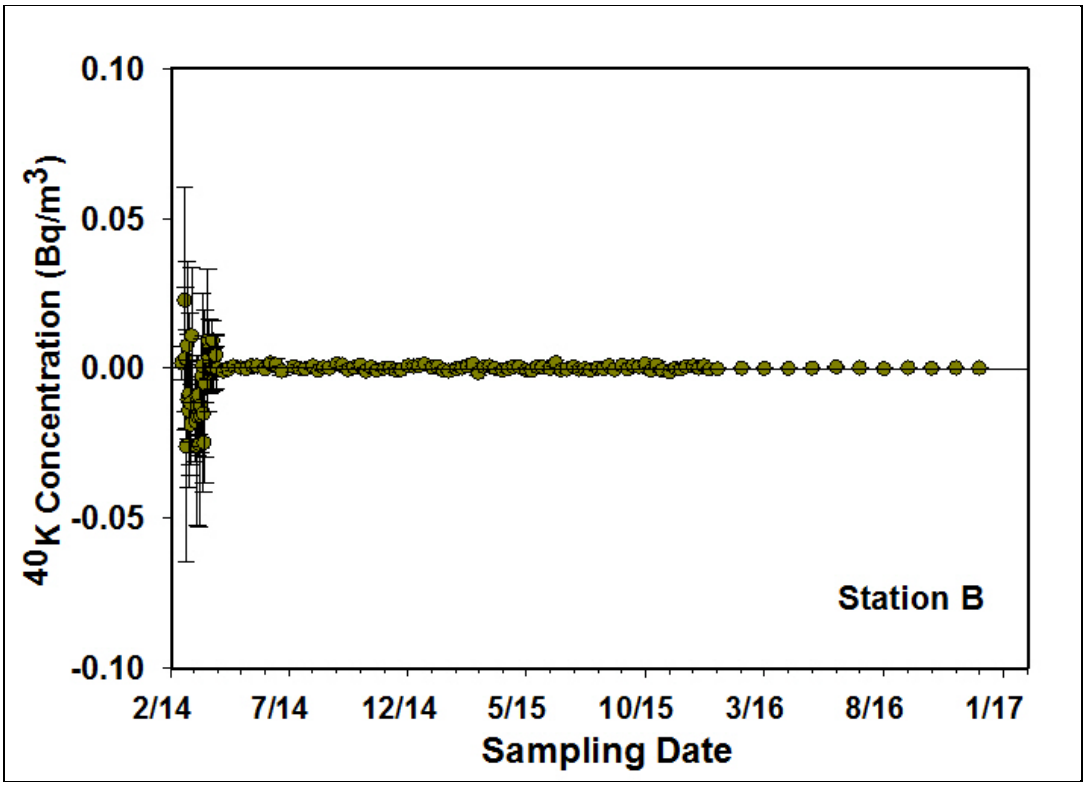


Figure 2-30: The ^{40}K Concentrations in the WIPP exhaust air at Station B (Post-HEPA)

Table 2-1: Weekly Activity concentrations of ^{241}Am (Bq/m^3) in Station A (Pre-HEPA) filters in 2016

Sample Date	^{241}Am Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
January 2016				
1st week	1.24E-03	1.62E-04	1.85E-06	Detected
2nd week	6.18E-04	8.51E-05	4.25E-06	Detected
3rd week	2.49E-04	3.90E-05	3.22E-06	Detected
4th week	5.35E-04	7.02E-05	2.18E-06	Detected
February 2016				
1st week	5.19E-04	6.90E-05	2.78E-06	Detected
2nd week	5.65E-04	7.41E-05	1.98E-06	Detected
3rd week	3.31E-04	4.40E-05	2.25E-06	Detected
4th week	2.04E-04	3.33E-05	3.82E-06	Detected
March 2016				
1st week	2.43E-04	3.30E-05	1.57E-06	Detected
2nd week	1.51E-04	2.17E-05	1.58E-06	Detected
3rd week	5.01E-04	6.40E-05	1.10E-06	Detected
4th week	3.44E-04	4.43E-05	1.01E-06	Detected
April 2016				
1st week	4.48E-04	5.96E-05	2.71E-06	Detected
2nd week	2.68E-04	3.73E-05	2.33E-06	Detected
3rd week	2.13E-04	2.91E-05	1.25E-06	Detected
4th week	2.38E-04	3.30E-05	1.71E-06	Detected
May 2016				
1st week	2.87E-04	3.75E-05	1.84E-06	Detected
2nd week	4.02E-04	5.16E-05	1.32E-06	Detected
3rd week	3.64E-04	4.73E-05	2.37E-06	Detected
4th week	3.98E-04	5.20E-05	2.05E-06	Detected
June 2016				
1st week	3.18E-04	4.31E-05	1.87E-06	Detected
2nd week	4.04E-04	5.94E-05	2.39E-06	Detected
3rd week	3.74E-04	4.93E-05	2.15E-06	Detected
4th week	2.79E-04	3.95E-05	2.87E-06	Detected
July 2016				
1st week	3.20E-04	4.22E-05	1.76E-06	Detected
2nd week	9.07E-04	1.14E-04	2.19E-06	Detected
3rd week	3.57E-04	4.70E-05	1.38E-06	Detected
4th week	3.74E-04	4.81E-05	1.51E-06	Detected

Table 2-1: Weekly Activity concentrations of ^{241}Am (Bq/m^3) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	^{241}Am Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
August 2016				
1st week	1.89E-04	2.52E-05	1.34E-06	Detected
2nd week	2.22E-04	3.45E-05	3.45E-06	Detected
3rd week	5.63E-04	7.01E-05	2.92E-06	Detected
4th week	3.24E-04	2.93E-05	1.33E-06	Detected
September 2016				
1st week	9.30E-04	5.80E-05	1.43E-06	Detected
2nd week	5.23E-04	3.33E-05	1.72E-06	Detected
3rd week	2.61E-04	1.11E-05	1.72E-06	Detected
4th week	2.56E-03	1.55E-04	1.41E-06	Detected
October 2016				
1st week	2.80E-03	1.49E-04	1.88E-06	Detected
2nd week	2.39E-03	1.22E-04	1.79E-06	Detected
3rd week	3.77E-03	1.89E-04	1.94E-06	Detected
4th week	2.57E-03	1.14E-04	1.31E-06	Detected
November 2016				
1st week	5.85E-03	5.94E-04	1.74E-06	Detected
2nd week	3.04E-03	3.64E-04	1.74E-06	Detected
3rd week	2.51E-03	3.07E-04	1.52E-06	Detected
4th week	1.78E-03	2.15E-04	1.29E-06	Detected
December 2016				
1st week	2.50E-03	2.97E-04	1.75E-06	Detected
2nd week	1.73E-03	2.17E-04	2.39E-06	Detected
3rd week	1.33E-03	1.61E-04	1.60E-06	Detected
4th week	1.36E-03	1.67E-04	1.37E-06	Detected

Table 2-2: Weekly Activity concentrations of $^{239+240}Pu$ (Bq/m^3) in Station A (Pre-HEPA) filters in 2016

Sample Date	$^{239+240}Pu$ Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
January 2016				
1st week	1.55E-04	2.21E-05	1.27E-06	Detected
2nd week	7.02E-05	1.18E-05	1.12E-06	Detected
3rd week	9.00E-05	1.41E-05	1.42E-06	Detected
4th week	2.05E-05	4.24E-06	1.04E-06	Detected
February 2016				
1st week	5.11E-05	9.08E-06	1.06E-06	Detected
2nd week	6.92E-05	1.15E-05	1.60E-06	Detected
3rd week	5.06E-05	9.80E-06	2.19E-06	Detected
4th week	3.16E-05	7.24E-06	1.37E-06	Detected
March 2016				
1st week	2.72E-05	5.47E-06	1.27E-06	Detected
2nd week	1.48E-05	3.96E-06	1.37E-06	Detected
3rd week	4.97E-05	8.85E-06	1.07E-06	Detected
4th week	3.84E-05	6.54E-06	6.91E-07	Detected
April 2016				
1st week	6.18E-05	1.10E-05	1.83E-06	Detected
2nd week	3.14E-05	6.41E-06	1.74E-06	Detected
3rd week	2.68E-05	5.81E-06	1.27E-06	Detected
4th week	2.80E-05	8.73E-06	2.51E-06	Detected
May 2016				
1st week	3.79E-05	7.40E-06	1.60E-06	Detected
2nd week	3.99E-05	7.73E-06	1.94E-06	Detected
3rd week	4.00E-05	7.86E-06	1.80E-06	Detected
4th week	4.50E-05	7.58E-06	9.03E-07	Detected
June 2016				
1st week	3.25E-05	6.45E-06	1.20E-06	Detected
2nd week	4.84E-05	9.07E-06	1.73E-06	Detected
3rd week	4.07E-05	7.63E-06	1.04E-06	Detected
4th week	3.94E-05	7.09E-06	1.44E-06	Detected
July 2016				
1st week	3.59E-05	9.04E-06	2.86E-06	Detected
2nd week	9.80E-05	1.87E-05	3.42E-06	Detected
3rd week	9.69E-05	1.53E-05	1.46E-06	Detected
4th week	4.75E-05	8.30E-06	1.37E-06	Detected

Table 2-2: Weekly Activity concentrations of $^{239+240}Pu$ (Bq/m^3) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	$^{239+240}Pu$ Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
August 2016				
1st week	2.92E-05	6.23E-06	1.39E-06	Detected
2nd week	2.94E-05	6.23E-06	1.37E-06	Detected
3rd week	1.67E-04	2.46E-05	2.47E-06	Detected
4th week	4.08E-05	6.26E-06	1.31E-06	Detected
September 2016				
1st week	1.11E-04	1.14E-05	1.53E-06	Detected
2nd week	1.83E-04	9.24E-06	1.61E-06	Detected
3rd week	3.30E-05	6.08E-06	1.54E-06	Detected
4th week	3.10E-04	2.35E-05	1.31E-06	Detected
October 2016				
1st week	3.67E-04	2.56E-05	1.66E-06	Detected
2nd week	2.92E-04	1.85E-05	1.59E-06	Detected
3rd week	5.05E-04	3.28E-05	1.58E-06	Detected
4th week	3.12E-04	1.94E-05	1.17E-06	Detected
November 2016				
1st week	6.24E-04	6.90E-05	1.88E-06	Detected
2nd week	2.97E-04	3.96E-05	2.49E-06	Detected
3rd week	4.66E-04	6.07E-05	1.94E-06	Detected
4th week	2.17E-04	2.91E-05	1.15E-06	Detected
December 2016				
1st week	3.33E-04	4.38E-05	1.42E-06	Detected
2nd week	2.03E-04	2.80E-05	1.61E-06	Detected
3rd week	1.59E-04	2.27E-05	1.44E-06	Detected
4th week	1.72E-04	2.32E-05	8.98E-07	Detected

Table 2-3: Weekly Activity concentrations of ^{238}Pu (Bq/m^3) in Station A (Pre-HEPA) filters in 2016

Sample Date	^{238}Pu Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
January 2016				
1st week	4.63E-06	2.15E-06	1.87E-06	Detected
2nd week	3.55E-06	1.92E-06	1.87E-06	Detected
3rd week	6.57E-06	2.51E-06	1.06E-06	Detected
4th week	2.26E-06	1.18E-06	7.14E-07	Detected
February 2016				
1st week	2.20E-06	1.43E-06	1.41E-06	Detected
2nd week	2.38E-06	1.49E-06	1.10E-06	Detected
3rd week	2.57E-06	1.81E-06	2.04E-06	Detected
4th week	3.50E-06	2.03E-06	1.37E-06	Detected
March 2016				
1st week	4.35E-06	1.83E-06	8.73E-07	Detected
2nd week	4.62E-06	2.06E-06	1.37E-06	Detected
3rd week	5.31E-06	2.23E-06	1.07E-06	Detected
4th week	5.04E-06	1.80E-06	9.24E-07	Detected
April 2016				
1st week	9.25E-06	3.29E-06	1.81E-06	Detected
2nd week	5.32E-06	2.24E-06	1.39E-06	Detected
3rd week	1.03E-05	3.25E-06	1.42E-06	Detected
4th week	8.95E-06	4.50E-06	2.51E-06	Detected
May 2016				
1st week	9.72E-06	3.22E-06	2.10E-06	Detected
2nd week	7.66E-06	2.80E-06	1.48E-06	Detected
3rd week	1.33E-05	3.90E-06	1.92E-06	Detected
4th week	1.32E-05	3.28E-06	1.19E-06	Detected
June 2016				
1st week	1.34E-05	3.69E-06	1.85E-06	Detected
2nd week	1.97E-05	5.03E-06	2.26E-06	Detected
3rd week	1.51E-05	4.00E-06	1.51E-06	Detected
4th week	7.15E-06	2.42E-06	1.26E-06	Detected
July 2016				
1st week	1.48E-05	5.49E-06	3.94E-06	Detected
2nd week	1.78E-05	6.49E-06	3.05E-06	Detected
3rd week	1.55E-05	4.36E-06	1.23E-06	Detected
4th week	1.61E-05	3.98E-06	1.10E-06	Detected

Table 2-3: Weekly Activity concentrations of ^{238}Pu (Bq/m^3) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	^{238}Pu Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
August 2016				
1st week	1.51E-05	4.24E-06	2.90E-06	Detected
2nd week	1.28E-05	3.85E-06	2.85E-06	Detected
3rd week	2.01E-05	5.83E-06	3.24E-06	Detected
4th week	1.19E-05	3.24E-06	1.62E-06	Detected
September 2016				
1st week	1.39E-05	3.74E-06	1.53E-06	Detected
2nd week	9.08E-06	3.22E-06	1.79E-06	Detected
3rd week	9.60E-06	3.27E-06	1.63E-06	Detected
4th week	2.25E-05	4.29E-06	1.33E-06	Detected
October 2016				
1st week	2.39E-05	5.10E-06	1.90E-06	Detected
2nd week	2.05E-05	4.50E-06	1.63E-06	Detected
3rd week	2.51E-05	5.16E-06	1.81E-06	Detected
4th week	1.63E-05	3.48E-06	1.18E-06	Detected
November 2016				
1st week	3.63E-05	6.76E-06	1.48E-06	Detected
2nd week	1.65E-05	4.32E-06	2.06E-06	Detected
3rd week	2.46E-05	5.56E-06	1.84E-06	Detected
4th week	9.93E-06	2.91E-06	1.43E-06	Detected
December 2016				
1st week	1.62E-05	4.24E-06	1.87E-06	Detected
2nd week	8.07E-06	2.86E-06	1.61E-06	Detected
3rd week	7.91E-06	2.71E-06	1.89E-06	Detected
4th week	8.75E-06	2.57E-06	1.25E-06	Detected

Table 2-4: Weekly Activity density of ^{241}Am (Bq/g) in Station A (Pre-HEPA) filters in 2016

Sample Date	^{241}Am Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
January 2016				
1st week	1.24E+01	1.62E+00	1.85E-02	Detected
2nd week	6.36E+00	8.75E-01	4.37E-02	Detected
3rd week	3.49E+00	5.46E-01	4.50E-02	Detected
4th week	5.52E+00	7.25E-01	2.26E-02	Detected
February 2016				
1st week	4.77E+00	6.33E-01	2.55E-02	Detected
2nd week	7.74E+00	1.01E+00	2.71E-02	Detected
3rd week	4.29E+00	5.70E-01	2.92E-02	Detected
4th week	4.13E+00	6.74E-01	7.74E-02	Detected
March 2016				
1st week	3.77E+00	5.12E-01	2.44E-02	Detected
2nd week	6.45E+00	9.24E-01	6.75E-02	Detected
3rd week	6.39E+00	8.17E-01	1.41E-02	Detected
4th week	4.15E+00	5.33E-01	1.22E-02	Detected
April 2016				
1st week	5.36E+00	7.13E-01	3.25E-02	Detected
2nd week	3.61E+00	5.03E-01	3.14E-02	Detected
3rd week	2.70E+00	3.69E-01	1.59E-02	Detected
4th week	4.17E+00	5.77E-01	3.00E-02	Detected
May 2016				
1st week	3.60E+00	4.71E-01	2.31E-02	Detected
2nd week	3.57E+00	4.58E-01	1.17E-02	Detected
3rd week	4.45E+00	5.78E-01	2.90E-02	Detected
4th week	3.34E+00	4.36E-01	1.72E-02	Detected
June 2016				
1st week	2.96E+00	4.02E-01	1.74E-02	Detected
2nd week	5.58E+00	8.20E-01	3.30E-02	Detected
3rd week	4.00E+00	5.27E-01	2.30E-02	Detected
4th week	2.28E+00	3.23E-01	2.35E-02	Detected
July 2016				
1st week	3.74E+00	4.93E-01	2.05E-02	Detected
2nd week	5.90E+00	7.39E-01	1.43E-02	Detected
3rd week	2.90E+00	3.82E-01	1.13E-02	Detected
4th week	2.84E+00	3.66E-01	1.15E-02	Detected

Table 2-4: Weekly Activity density of ^{241}Am (Bq/g) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	^{241}Am Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
August 2016				
1st week	1.04E+00	1.39E-01	7.38E-03	Detected
2nd week	1.39E+00	2.16E-01	2.16E-02	Detected
3rd week	3.41E+00	4.24E-01	1.76E-02	Detected
4th week	3.10E+00	2.81E-01	1.27E-02	Detected
September 2016				
1st week	7.78E+00	4.85E-01	1.20E-02	Detected
2nd week	5.84E+00	3.71E-01	1.91E-02	Detected
3rd week	2.96E+00	1.27E-01	1.96E-02	Detected
4th week	2.95E+01	1.79E+00	1.62E-02	Detected
October 2016				
1st week	3.27E+01	1.74E+00	2.20E-02	Detected
2nd week	2.89E+01	1.48E+00	2.17E-02	Detected
3rd week	3.72E+01	1.87E+00	1.91E-02	Detected
4th week	2.14E+01	9.51E-01	1.09E-02	Detected
November 2016				
1st week	7.71E+01	7.82E+00	2.29E-02	Detected
2nd week	2.82E+01	3.38E+00	1.61E-02	Detected
3rd week	1.26E+01	1.55E+00	7.65E-03	Detected
4th week	1.12E+01	1.35E+00	8.15E-03	Detected
December 2016				
1st week	1.64E+01	1.96E+00	1.15E-02	Detected
2nd week	9.26E+00	1.16E+00	1.28E-02	Detected
3rd week	8.81E+00	1.07E+00	1.06E-02	Detected
4th week	9.38E+00	1.15E+00	9.45E-03	Detected

Table 2-5: Weekly Activity density of $^{239+240}$Pu (Bq/g) in Station A (Pre-HEPA) filters in 2016

Sample Date	$^{239+240}$Pu Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
January 2016				
1st week	1.55E+00	2.21E-01	1.27E-02	Detected
2nd week	7.22E-01	1.21E-01	1.16E-02	Detected
3rd week	1.26E+00	1.97E-01	1.99E-02	Detected
4th week	2.12E-01	4.38E-02	1.07E-02	Detected
February 2016				
1st week	4.70E-01	8.34E-02	9.69E-03	Detected
2nd week	9.47E-01	1.58E-01	2.19E-02	Detected
3rd week	6.55E-01	1.27E-01	2.83E-02	Detected
4th week	6.41E-01	1.47E-01	2.77E-02	Detected
March 2016				
1st week	4.22E-01	8.48E-02	1.97E-02	Detected
2nd week	6.28E-01	1.69E-01	5.85E-02	Detected
3rd week	6.35E-01	1.13E-01	1.36E-02	Detected
4th week	4.62E-01	7.88E-02	8.32E-03	Detected
April 2016				
1st week	7.40E-01	1.32E-01	2.19E-02	Detected
2nd week	4.23E-01	8.63E-02	2.34E-02	Detected
3rd week	3.40E-01	7.35E-02	1.60E-02	Detected
4th week	4.90E-01	1.53E-01	4.39E-02	Detected
May 2016				
1st week	4.75E-01	9.28E-02	2.00E-02	Detected
2nd week	3.54E-01	6.85E-02	1.72E-02	Detected
3rd week	4.90E-01	9.61E-02	2.21E-02	Detected
4th week	3.78E-01	6.36E-02	7.58E-03	Detected
June 2016				
1st week	3.03E-01	6.01E-02	1.12E-02	Detected
2nd week	6.69E-01	1.25E-01	2.38E-02	Detected
3rd week	4.35E-01	8.16E-02	1.11E-02	Detected
4th week	3.23E-01	5.81E-02	1.18E-02	Detected
July 2016				
1st week	4.19E-01	1.06E-01	3.34E-02	Detected
2nd week	6.38E-01	1.22E-01	2.23E-02	Detected
3rd week	7.88E-01	1.24E-01	1.19E-02	Detected
4th week	3.61E-01	6.32E-02	1.04E-02	Detected

Table 2-5: Weekly Activity density of $^{239+240}$Pu (Bq/g) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	$^{239+240}$Pu Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
August 2016				
1st week	1.61E-01	3.44E-02	7.64E-03	Detected
2nd week	1.84E-01	3.90E-02	8.55E-03	Detected
3rd week	1.01E+00	1.49E-01	1.49E-02	Detected
4th week	3.91E-01	6.00E-02	1.25E-02	Detected
September 2016				
1st week	9.26E-01	9.56E-02	1.28E-02	Detected
2nd week	2.05E+00	1.03E-01	1.80E-02	Detected
3rd week	3.75E-01	6.91E-02	1.75E-02	Detected
4th week	3.57E+00	2.70E-01	1.51E-02	Detected
October 2016				
1st week	4.29E+00	2.99E-01	1.94E-02	Detected
2nd week	3.53E+00	2.25E-01	1.93E-02	Detected
3rd week	4.98E+00	3.23E-01	1.56E-02	Detected
4th week	2.60E+00	1.62E-01	9.76E-03	Detected
November 2016				
1st week	8.22E+00	9.09E-01	2.48E-02	Detected
2nd week	2.75E+00	3.68E-01	2.31E-02	Detected
3rd week	2.35E+00	3.05E-01	9.75E-03	Detected
4th week	1.37E+00	1.84E-01	7.22E-03	Detected
December 2016				
1st week	2.19E+00	2.89E-01	9.38E-03	Detected
2nd week	1.09E+00	1.50E-01	8.59E-03	Detected
3rd week	1.05E+00	1.50E-01	9.55E-03	Detected
4th week	1.18E+00	1.60E-01	6.19E-03	Detected

Table 2-6: Weekly Activity density of ^{238}Pu (Bq/g) in Station A (Pre-HEPA) filters in 2016

Sample Date	^{238}Pu Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
January 2016				
1st week	4.63E-02	2.15E-02	1.87E-02	Detected
2nd week	3.65E-02	1.98E-02	1.92E-02	Detected
3rd week	9.21E-02	3.51E-02	1.49E-02	Detected
4th week	2.34E-02	1.22E-02	7.37E-03	Detected
February 2016				
1st week	2.02E-02	1.32E-02	1.29E-02	Detected
2nd week	3.25E-02	2.04E-02	1.50E-02	Detected
3rd week	3.34E-02	2.35E-02	2.64E-02	Detected
4th week	7.09E-02	4.12E-02	2.77E-02	Detected
March 2016				
1st week	6.74E-02	2.84E-02	1.35E-02	Detected
2nd week	1.97E-01	8.79E-02	5.85E-02	Detected
3rd week	6.78E-02	2.85E-02	1.36E-02	Detected
4th week	6.07E-02	2.16E-02	1.11E-02	Detected
April 2016				
1st week	1.11E-01	3.93E-02	2.17E-02	Detected
2nd week	7.16E-02	3.01E-02	1.88E-02	Detected
3rd week	1.31E-01	4.11E-02	1.80E-02	Detected
4th week	1.57E-01	7.88E-02	4.39E-02	Detected
May 2016				
1st week	1.22E-01	4.04E-02	2.63E-02	Detected
2nd week	6.79E-02	2.48E-02	1.31E-02	Detected
3rd week	1.63E-01	4.76E-02	2.34E-02	Detected
4th week	1.11E-01	2.75E-02	9.97E-03	Detected
June 2016				
1st week	1.25E-01	3.44E-02	1.73E-02	Detected
2nd week	2.73E-01	6.94E-02	3.13E-02	Detected
3rd week	1.61E-01	4.27E-02	1.62E-02	Detected
4th week	5.85E-02	1.98E-02	1.03E-02	Detected
July 2016				
1st week	1.72E-01	6.41E-02	4.60E-02	Detected
2nd week	1.16E-01	4.22E-02	1.98E-02	Detected
3rd week	1.26E-01	3.55E-02	9.99E-03	Detected
4th week	1.22E-01	3.03E-02	8.37E-03	Detected

Table 2-6: Weekly Activity density of ^{238}Pu (Bq/g) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	^{238}Pu Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
August 2016				
1st week	8.32E-02	2.34E-02	1.60E-02	Detected
2nd week	8.00E-02	2.41E-02	1.78E-02	Detected
3rd week	1.22E-01	3.53E-02	1.96E-02	Detected
4th week	1.14E-01	3.10E-02	1.55E-02	Detected
September 2016				
1st week	1.16E-01	3.13E-02	1.28E-02	Detected
2nd week	1.01E-01	3.60E-02	2.00E-02	Detected
3rd week	1.09E-01	3.72E-02	1.85E-02	Detected
4th week	2.59E-01	4.94E-02	1.53E-02	Detected
October 2016				
1st week	2.80E-01	5.96E-02	2.22E-02	Detected
2nd week	2.48E-01	5.45E-02	1.97E-02	Detected
3rd week	2.48E-01	5.09E-02	1.78E-02	Detected
4th week	1.36E-01	2.90E-02	9.83E-03	Detected
November 2016				
1st week	4.78E-01	8.90E-02	1.95E-02	Detected
2nd week	1.53E-01	4.01E-02	1.91E-02	Detected
3rd week	1.24E-01	2.80E-02	9.25E-03	Detected
4th week	6.26E-02	1.84E-02	8.99E-03	Detected
December 2016				
1st week	1.06E-01	2.79E-02	1.23E-02	Detected
2nd week	4.32E-02	1.53E-02	8.59E-03	Detected
3rd week	5.25E-02	1.80E-02	1.25E-02	Detected
4th week	6.03E-02	1.77E-02	8.64E-03	Detected

Table 2-7: Monthly Activity concentrations of ^{241}Am (Bq/m^3) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	^{241}Am Activity Bq/m^3	Unc.(2σ) Bq/m^3	MDC Bq/m^3	Status
^{241}Am	January	5.04E-05	6.84E-06	2.29E-07	Detected
	February	9.07E-06	2.27E-06	5.39E-07	Detected
	March	1.28E-05	2.22E-06	3.60E-07	Detected
	April	1.84E-05	3.16E-06	4.48E-07	Detected
	May	3.80E-06	9.35E-07	3.21E-07	Detected
	June	1.00E-05	1.86E-06	3.77E-07	Detected
	July	7.03E-05	9.27E-06	3.24E-07	Detected
	August	1.91E-05	3.25E-06	1.52E-06	Detected
	September	1.43E-05	1.84E-06	3.79E-07	Detected
	October	3.35E-06	9.04E-07	4.21E-07	Detected
	November	3.83E-05	5.32E-06	3.45E-07	Detected
	December	9.03E-06	1.74E-06	3.71E-07	Detected

Table 2-8: Monthly Activity concentrations of $^{239+240}Pu$ (Bq/m^3) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	$^{239+240}Pu$ Activity Bq/m^3	Unc.(2σ) Bq/m^3	MDC Bq/m^3	Status
$^{239+240}Pu$	January	5.48E-06	1.19E-06	3.23E-07	Detected
	February	1.32E-06	5.56E-07	2.65E-07	Detected
	March	1.98E-06	6.55E-07	4.53E-07	Detected
	April	1.85E-06	7.01E-07	3.46E-07	Detected
	May	6.75E-07	3.76E-07	2.44E-07	Detected
	June	1.04E-06	4.53E-07	3.38E-07	Detected
	July	7.70E-06	1.51E-06	3.31E-07	Detected
	August	2.25E-06	7.20E-07	1.28E-06	Detected
	September	2.51E-06	9.20E-07	3.61E-07	Detected
	October	3.99E-07	2.91E-07	3.16E-07	Detected
	November	4.94E-06	1.18E-06	4.80E-07	Detected
	December	1.04E-06	4.73E-07	3.22E-07	Detected

Table 2-9: Monthly Activity concentrations of ^{238}Pu (Bq/m^3) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	^{238}Pu Activity Bq/m^3	Unc.(2σ) Bq/m^3	MDC Bq/m^3	Status
^{238}Pu	January	2.13E-07	2.02E-07	2.22E-07	Not Detected
	February	2.13E-08	1.62E-07	4.87E-07	Not Detected
	March	9.71E-08	1.57E-07	3.21E-07	Not Detected
	April	2.10E-07	2.69E-07	5.10E-07	Not Detected
	May	-3.92E-08	1.14E-07	4.67E-07	Not Detected
	June	8.68E-08	1.55E-07	3.38E-07	Not Detected
	July	4.64E-07	3.09E-07	3.31E-07	Detected
	August	4.86E-08	2.95E-07	1.62E-06	Not Detected
	September	1.06E-08	1.14E-07	3.86E-07	Not Detected
	October	7.60E-08	1.37E-07	2.82E-07	Not Detected
	November	2.22E-07	2.77E-07	5.50E-07	Not Detected
	December	2.90E-08	1.46E-07	4.23E-07	Not Detected

Table 2-10: Monthly Activity density of ^{241}Am (Bq/g) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	^{241}Am Activity Bq/g	Unc.(2σ) Bq/g	MDC Bq/g	Status
^{241}Am	January	7.10E+00	9.65E-01	3.23E-02	Detected
	February	2.48E+00	6.21E-01	1.47E-01	Detected
	March	2.06E+00	3.58E-01	5.83E-02	Detected
	April	2.88E+00	4.95E-01	7.02E-02	Detected
	May	4.06E-01	1.00E-01	3.43E-02	Detected
	June	1.48E+00	2.73E-01	5.56E-02	Detected
	July	9.59E+00	1.26E+00	4.42E-02	Detected
	August	1.71E+00	2.90E-01	1.36E-01	Detected
	September	5.58E+00	7.17E-01	1.48E-01	Detected
	October	4.27E-01	1.15E-01	5.36E-02	Detected
	November	4.28E+00	5.94E-01	3.86E-02	Detected
	December	1.83E+00	3.54E-01	7.54E-02	Detected

Table 2-11: Monthly Activity density of $^{239+240}$Pu (Bq/g) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	$^{239+240}$Pu Activity Bq/g	Unc.(2σ) Bq/g	MDC Bq/g	Status
$^{239+240}$Pu	January	7.72E-01	1.68E-01	4.55E-02	Detected
	February	3.60E-01	1.52E-01	7.26E-02	Detected
	March	3.20E-01	1.06E-01	7.33E-02	Detected
	April	2.89E-01	1.10E-01	5.42E-02	Detected
	May	7.22E-02	4.02E-02	2.61E-02	Detected
	June	1.54E-01	6.67E-02	4.98E-02	Detected
	July	1.05E+00	2.05E-01	4.51E-02	Detected
	August	2.01E-01	6.43E-02	1.14E-01	Detected
	September	9.77E-01	3.59E-01	1.41E-01	Detected
	October	5.08E-02	3.71E-02	4.03E-02	Detected
	November	5.52E-01	1.32E-01	5.37E-02	Detected
	December	2.11E-01	9.60E-02	6.54E-02	Detected

Table 2-12: Monthly Activity density of ^{238}Pu (Bq/g) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	^{238}Pu Activity Bq/g	Unc.(2σ) Bq/g	MDC Bq/g	Status
^{238}Pu	January	3.00E-02	2.84E-02	3.12E-02	Not Detected
	February	5.82E-03	4.44E-02	1.33E-01	Not Detected
	March	1.57E-02	2.55E-02	5.19E-02	Not Detected
	April	3.28E-02	4.22E-02	7.98E-02	Not Detected
	May	-4.19E-03	1.22E-02	5.00E-02	Not Detected
	June	1.28E-02	2.29E-02	4.98E-02	Not Detected
	July	6.32E-02	4.21E-02	4.51E-02	Detected
	August	4.34E-03	2.64E-02	1.44E-01	Not Detected
	September	4.14E-03	4.45E-02	1.51E-01	Not Detected
	October	9.68E-03	1.74E-02	3.59E-02	Not Detected
	November	2.48E-02	3.10E-02	6.15E-02	Not Detected
	December	5.90E-03	2.97E-02	8.60E-02	Not Detected

Table 2-13: Monthly Activity concentrations of Uranium Isotopes in Station A (Pre-HEPA) filters in 2016

Radionuclides	Sample Date	Activity Bq/m^3	Unc.(2σ) Bq/m^3	MDC Bq/m^3	Status
^{234}U	January	7.00E-07	2.86E-07	4.03E-07	Detected
	February	7.49E-07	2.97E-07	2.90E-07	Detected
	March	6.66E-07	2.86E-07	4.05E-07	Detected
	April	6.65E-07	2.88E-07	3.63E-07	Detected
	May	1.05E-06	3.52E-07	3.60E-07	Detected
	June	1.09E-06	3.87E-07	5.32E-07	Detected
	July	4.60E-07	3.80E-07	7.22E-07	Not Detected
	August	5.92E-07	4.11E-07	7.44E-07	Not Detected
	September	8.81E-07	4.39E-07	6.40E-07	Detected
	October	1.21E-06	4.73E-07	6.27E-07	Detected
	November	7.34E-07	4.08E-07	6.71E-07	Detected
	December	9.34E-07	3.77E-07	4.49E-07	Detected
^{235}U	January	1.40E-07	1.33E-07	2.17E-07	Not Detected
	February	2.99E-07	2.09E-07	2.77E-07	Detected
	March	2.24E-07	1.82E-07	2.99E-07	Not Detected
	April	1.69E-07	1.96E-07	3.99E-07	Not Detected
	May	3.93E-07	2.42E-07	3.38E-07	Detected
	June	3.75E-07	2.31E-07	3.22E-07	Detected
	July	9.45E-08	2.33E-07	5.67E-07	Not Detected
	August	2.28E-07	2.75E-07	5.48E-07	Not Detected
	September	1.36E-07	2.40E-07	5.43E-07	Not Detected
	October	7.69E-08	2.17E-07	5.42E-07	Not Detected
	November	4.11E-08	1.85E-07	4.95E-07	Not Detected
	December	0.00E+00	1.40E-07	4.20E-07	Not Detected
^{238}U	January	5.85E-07	2.61E-07	3.79E-07	Detected
	February	5.29E-07	2.61E-07	3.40E-07	Detected
	March	3.01E-07	2.19E-07	4.04E-07	Not Detected
	April	2.96E-07	2.80E-07	5.81E-07	Not Detected
	May	4.07E-07	2.75E-07	5.09E-07	Not Detected
	June	6.06E-07	2.74E-07	3.77E-07	Detected
	July	6.10E-07	3.65E-07	5.38E-07	Detected
	August	3.67E-07	4.56E-07	1.00E-06	Not Detected
	September	2.93E-07	3.88E-07	8.60E-07	Not Detected
	October	1.24E-07	4.11E-07	9.96E-07	Not Detected
	November	3.66E-07	3.48E-07	7.08E-07	Not Detected
	December	3.10E-07	2.95E-07	6.00E-07	Not Detected

Table 2-14: Monthly Activity density of Uranium Isotopes in Station A (Pre-HEPA) filters in 2016

Radionuclides	Sample Date	Activity Bq/g	Unc.(2σ) Bq/g	MDC Bq/g	Status
^{234}U	January	7.63E-03	3.12E-03	4.39E-03	Detected
	February	9.86E-03	3.91E-03	3.82E-03	Detected
	March	1.04E-02	4.47E-03	6.33E-03	Detected
	April	9.21E-03	3.99E-03	5.03E-03	Detected
	May	1.04E-02	3.51E-03	3.59E-03	Detected
	June	1.09E-02	3.86E-03	5.32E-03	Detected
	July	3.73E-03	3.08E-03	5.85E-03	Not Detected
	August	3.99E-03	2.77E-03	5.02E-03	Not Detected
	September	9.23E-03	4.60E-03	6.70E-03	Detected
	October	1.22E-02	4.75E-03	6.29E-03	Detected
	November	5.38E-03	2.99E-03	4.92E-03	Detected
	December	5.94E-03	2.40E-03	2.86E-03	Detected
^{235}U	January	1.53E-03	1.45E-03	2.37E-03	Not Detected
	February	3.93E-03	2.75E-03	3.65E-03	Detected
	March	3.49E-03	2.84E-03	4.67E-03	Not Detected
	April	2.34E-03	2.71E-03	5.52E-03	Not Detected
	May	3.91E-03	2.41E-03	3.36E-03	Detected
	June	3.74E-03	2.31E-03	3.21E-03	Detected
	July	7.67E-04	1.89E-03	4.60E-03	Not Detected
	August	1.54E-03	1.86E-03	3.70E-03	Not Detected
	September	1.42E-03	2.52E-03	5.69E-03	Not Detected
	October	7.72E-04	2.18E-03	5.44E-03	Not Detected
	November	3.01E-04	1.35E-03	3.62E-03	Not Detected
	December	0.00E+00	8.88E-04	2.67E-03	Not Detected
^{238}U	January	6.37E-03	2.84E-03	4.13E-03	Detected
	February	6.97E-03	3.44E-03	4.48E-03	Detected
	March	4.69E-03	3.41E-03	6.30E-03	Not Detected
	April	4.11E-03	3.87E-03	8.05E-03	Not Detected
	May	4.05E-03	2.74E-03	5.07E-03	Not Detected
	June	6.05E-03	2.74E-03	3.76E-03	Detected
	July	4.95E-03	2.96E-03	4.36E-03	Detected
	August	2.48E-03	3.08E-03	6.78E-03	Not Detected
	September	3.07E-03	4.06E-03	9.00E-03	Not Detected
	October	1.25E-03	4.13E-03	9.99E-03	Not Detected
	November	2.68E-03	2.55E-03	5.19E-03	Not Detected
	December	1.97E-03	1.88E-03	3.82E-03	Not Detected

Table 2-15: Monthly Activity concentrations of Uranium Isotopes in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	Activity Bq/m^3	Unc.(2σ) Bq/m^3	MDC Bq/m^3	Status
^{234}U	January	4.42E-07	2.86E-07	4.45E-07	Not Detected
	February	6.79E-07	3.80E-07	5.92E-07	Detected
	March	1.31E-06	6.09E-07	9.27E-07	Detected
	April	2.16E-07	3.16E-07	6.98E-07	Not Detected
	May	1.41E-07	3.15E-07	7.49E-07	Not Detected
	June	2.02E-07	2.28E-07	4.76E-07	Not Detected
	July	1.98E-07	2.63E-07	5.81E-07	Not Detected
	August	5.00E-06	1.08E-06	8.57E-07	Detected
	September	4.08E-07	2.54E-07	4.18E-07	Not Detected
	October	7.45E-07	3.51E-07	4.39E-07	Detected
	November	8.99E-07	3.92E-07	5.22E-07	Detected
	December	4.66E-07	3.72E-07	7.32E-07	Not Detected
^{235}U	January	6.01E-07	3.37E-07	5.24E-07	Detected
	February	8.38E-08	2.37E-07	5.92E-07	Not Detected
	March	2.68E-07	3.88E-07	8.52E-07	Not Detected
	April	9.18E-08	1.84E-07	4.26E-07	Not Detected
	May	2.16E-07	3.14E-07	6.89E-07	Not Detected
	June	9.36E-08	9.22E-08	2.90E-07	Not Detected
	July	9.15E-08	2.21E-07	5.32E-07	Not Detected
	August	8.49E-07	4.52E-07	5.66E-07	Detected
	September	5.92E-08	1.68E-07	4.18E-07	Not Detected
	October	3.84E-08	1.33E-07	3.55E-07	Not Detected
	November	4.81E-07	3.27E-07	5.22E-07	Not Detected
	December	1.54E-07	2.43E-07	5.42E-07	Not Detected
^{238}U	January	2.19E-07	3.03E-07	6.69E-07	Not Detected
	February	-3.39E-08	3.11E-07	8.29E-07	Not Detected
	March	1.74E-07	4.90E-07	1.18E-06	Not Detected
	April	1.47E-07	2.77E-07	6.43E-07	Not Detected
	May	2.10E-07	4.10E-07	9.58E-07	Not Detected
	June	1.26E-07	3.31E-07	7.91E-07	Not Detected
	July	-2.71E-07	3.60E-07	9.83E-07	Not Detected
	August	1.90E-07	6.42E-07	1.54E-06	Not Detected
	September	4.79E-08	2.35E-07	5.87E-07	Not Detected
	October	-3.10E-08	2.23E-07	6.23E-07	Not Detected
	November	3.58E-07	4.06E-07	8.89E-07	Not Detected
	December	2.17E-07	2.57E-07	5.40E-07	Not Detected

Table 2-16: Monthly Activity density of Uranium Isotopes in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	Activity Bq/g	Unc.(2σ) Bq/g	MDC Bq/g	Status
^{234}U	January	6.23E-02	4.03E-02	6.27E-02	Not Detected
	February	1.86E-01	1.04E-01	1.62E-01	Detected
	March	2.12E-01	9.90E-02	1.51E-01	Detected
	April	3.38E-02	4.95E-02	1.09E-01	Not Detected
	May	1.51E-02	3.37E-02	8.01E-02	Not Detected
	June	2.98E-02	3.35E-02	7.01E-02	Not Detected
	July	2.70E-02	3.58E-02	7.92E-02	Not Detected
	August	4.47E-01	9.67E-02	7.65E-02	Detected
	September	1.59E-01	9.89E-02	1.63E-01	Not Detected
	October	9.50E-02	4.47E-02	5.59E-02	Detected
	November	1.00E-01	4.38E-02	5.83E-02	Detected
	December	9.47E-02	7.56E-02	1.49E-01	Not Detected
^{235}U	January	8.47E-02	4.75E-02	7.38E-02	Detected
	February	2.29E-02	6.49E-02	1.62E-01	Not Detected
	March	4.35E-02	6.31E-02	1.39E-01	Not Detected
	April	1.44E-02	2.88E-02	6.67E-02	Not Detected
	May	2.31E-02	3.35E-02	7.37E-02	Not Detected
	June	1.38E-02	1.36E-02	4.27E-02	Not Detected
	July	1.25E-02	3.01E-02	7.25E-02	Not Detected
	August	7.58E-02	4.04E-02	5.05E-02	Detected
	September	2.31E-02	6.53E-02	1.63E-01	Not Detected
	October	4.89E-03	1.69E-02	4.53E-02	Not Detected
	November	5.37E-02	3.65E-02	5.83E-02	Not Detected
	December	3.12E-02	4.94E-02	1.10E-01	Not Detected
^{238}U	January	3.09E-02	4.27E-02	9.43E-02	Not Detected
	February	-9.26E-03	8.50E-02	2.27E-01	Not Detected
	March	2.83E-02	7.97E-02	1.92E-01	Not Detected
	April	2.31E-02	4.34E-02	1.01E-01	Not Detected
	May	2.25E-02	4.38E-02	1.02E-01	Not Detected
	June	1.85E-02	4.88E-02	1.17E-01	Not Detected
	July	-3.69E-02	4.91E-02	1.34E-01	Not Detected
	August	1.69E-02	5.73E-02	1.38E-01	Not Detected
	September	1.87E-02	9.14E-02	2.29E-01	Not Detected
	October	-3.95E-03	2.85E-02	7.94E-02	Not Detected
	November	3.99E-02	4.54E-02	9.93E-02	Not Detected
	December	4.40E-02	5.23E-02	1.10E-01	Not Detected

Table 2-17: Weekly Activity concentrations of ^{137}Cs (Bq/m^3) in Station A (Pre-HEPA) filters in 2016

Sample Date	^{137}Cs Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
January 2016				
1st week	-1.94E-06	8.56E-05	2.86E-04	Not Detected
2nd week	2.00E-04	8.18E-05	2.67E-04	Not Detected
3rd week	-6.66E-06	8.16E-05	2.72E-04	Not Detected
4th week	-1.06E-05	5.66E-05	1.89E-04	Not Detected
February 2016				
1st week	1.13E-04	8.35E-05	2.75E-04	Not Detected
2nd week	5.26E-05	8.03E-05	2.67E-04	Not Detected
3rd week	3.17E-05	1.04E-04	3.45E-04	Not Detected
4th week	1.93E-05	7.21E-05	2.40E-04	Not Detected
March 2016				
1st week	-8.92E-05	8.33E-05	2.80E-04	Not Detected
2nd week	1.11E-04	8.10E-05	2.67E-04	Not Detected
3rd week	-8.30E-05	8.94E-05	3.00E-04	Not Detected
4th week	-2.54E-06	5.82E-05	1.94E-04	Not Detected
April 2016				
1st week	1.10E-05	8.57E-05	2.88E-04	Not Detected
2nd week	1.42E-04	8.04E-05	2.64E-04	Not Detected
3rd week	9.59E-05	8.60E-05	2.84E-04	Not Detected
4th week	1.42E-04	6.24E-05	2.04E-04	Not Detected
May 2016				
1st week	5.26E-05	1.04E-04	3.47E-04	Not Detected
2nd week	-7.47E-05	7.66E-05	2.55E-04	Not Detected
3rd week	-1.73E-04	1.10E-04	3.71E-04	Not Detected
4th week	-6.25E-05	7.65E-05	2.56E-04	Not Detected
June 2016				
1st week	8.04E-06	8.24E-05	2.75E-04	Not Detected
2nd week	1.17E-04	8.21E-05	2.71E-04	Not Detected
3rd week	6.83E-06	8.50E-05	2.83E-04	Not Detected
4th week	7.46E-05	6.82E-05	2.25E-04	Not Detected
July 2016				
1st week	6.35E-05	1.11E-04	3.69E-04	Not Detected
2nd week	2.09E-04	1.19E-04	3.90E-04	Not Detected
3rd week	1.06E-04	9.48E-05	3.13E-04	Not Detected
4th week	4.37E-05	7.04E-05	2.34E-04	Not Detected

Table 2-17: Weekly Activity concentrations of ^{137}Cs (Bq/m^3) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	^{137}Cs Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
August 2016				
1st week	5.16E-05	8.43E-05	2.80E-04	Not Detected
2nd week	1.30E-04	9.71E-04	3.25E-03	Not Detected
3rd week	6.98E-04	1.43E-03	4.76E-03	Not Detected
4th week	3.64E-04	7.77E-04	2.59E-03	Not Detected
September 2016				
1st week	-8.00E-06	8.22E-05	2.75E-04	Not Detected
2nd week	-3.77E-05	1.05E-04	3.50E-04	Not Detected
3rd week	3.09E-05	8.55E-05	2.84E-04	Not Detected
4th week	-1.43E-04	8.45E-05	2.84E-04	Not Detected
October 2016				
1st week	-3.03E-05	8.35E-05	2.80E-04	Not Detected
2nd week	-6.90E-06	1.09E-04	3.63E-04	Not Detected
3rd week	2.25E-04	2.01E-04	6.64E-04	Not Detected
4th week	1.08E-05	5.75E-05	1.92E-04	Not Detected
November 2016				
1st week	-1.06E-05	8.00E-05	2.67E-04	Not Detected
2nd week	4.43E-05	8.15E-05	2.71E-04	Not Detected
3rd week	9.54E-05	1.05E-04	3.48E-04	Not Detected
4th week	4.38E-05	1.55E-04	5.18E-04	Not Detected
December 2016				
1st week	-9.99E-05	8.76E-05	2.95E-04	Not Detected
2nd week	1.41E-04	1.08E-04	3.55E-04	Not Detected
3rd week	-5.00E-05	8.38E-05	2.81E-04	Not Detected
4th week	4.82E-05	7.46E-05	2.47E-04	Not Detected

Table 2-18: Weekly Activity concentrations of ^{40}K (Bq/m^3) in Station A (Pre-HEPA) filters in 2016

Sample Date	^{40}K Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
January 2016				
1st week	-8.00E-04	1.06E-03	3.57E-03	Not Detected
2nd week	-9.84E-04	1.01E-03	3.42E-03	Not Detected
3rd week	-6.82E-04	1.01E-03	3.41E-03	Not Detected
4th week	-2.92E-04	6.96E-04	2.34E-03	Not Detected
February 2016				
1st week	-5.94E-04	1.01E-03	3.42E-03	Not Detected
2nd week	8.53E-04	9.94E-04	3.30E-03	Not Detected
3rd week	-1.69E-04	1.10E-04	3.77E-04	Not Detected
4th week	9.02E-04	8.21E-04	2.72E-03	Not Detected
March 2016				
1st week	1.42E-03	9.53E-04	2.74E-04	Not Detected
2nd week	-3.98E-05	9.68E-04	3.25E-03	Not Detected
3rd week	-2.14E-04	1.06E-03	3.56E-03	Not Detected
4th week	-2.52E-04	7.03E-04	2.37E-03	Not Detected
April 2016				
1st week	-1.91E-03	1.14E-03	3.87E-03	Not Detected
2nd week	-3.91E-04	1.00E-03	3.37E-03	Not Detected
3rd week	1.10E-03	1.01E-03	3.33E-03	Not Detected
4th week	4.35E-04	7.66E-04	2.55E-03	Not Detected
May 2016				
1st week	-1.22E-03	1.08E-03	3.64E-03	Not Detected
2nd week	-4.90E-04	8.08E-04	2.70E-03	Not Detected
3rd week	-3.87E-04	1.06E-03	3.57E-03	Not Detected
4th week	-3.89E-04	7.52E-04	2.53E-03	Not Detected
June 2016				
1st week	1.23E-03	9.70E-04	3.21E-03	Not Detected
2nd week	-1.17E-04	9.93E-04	3.33E-03	Not Detected
3rd week	-3.28E-04	1.04E-03	3.49E-03	Not Detected
4th week	-4.24E-04	8.11E-04	2.74E-03	Not Detected
July 2016				
1st week	-5.63E-04	1.11E-03	3.72E-03	Not Detected
2nd week	-4.24E-04	1.21E-03	4.08E-03	Not Detected
3rd week	-6.15E-04	1.20E-03	4.03E-03	Not Detected
4th week	-3.82E-04	8.87E-04	2.99E-03	Not Detected

Table 2-18: Weekly Activity concentrations of ^{40}K (Bq/m^3) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	^{40}K Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
August 2016				
1st week	1.90E-03	1.02E-03	3.35E-03	Not Detected
2nd week	1.30E-04	9.71E-04	3.25E-03	Not Detected
3rd week	6.98E-04	1.43E-03	4.76E-03	Not Detected
4th week	3.64E-04	7.77E-04	2.59E-03	Not Detected
September 2016				
1st week	-1.36E-03	1.02E-03	3.47E-03	Not Detected
2nd week	-1.80E-06	1.04E-03	3.48E-03	Not Detected
3rd week	-7.02E-04	1.07E-04	3.60E-03	Not Detected
4th week	-4.01E-04	8.15E-04	2.75E-03	Not Detected
October 2016				
1st week	4.51E-04	9.98E-04	3.33E-03	Not Detected
2nd week	6.23E-04	1.04E-03	3.45E-03	Not Detected
3rd week	-5.22E-04	2.03E-03	6.88E-03	Not Detected
4th week	2.43E-04	6.92E-04	2.31E-03	Not Detected
November 2016				
1st week	9.69E-04	9.29E-04	3.08E-03	Not Detected
2nd week	4.07E-04	9.77E-05	3.26E-03	Not Detected
3rd week	7.54E-04	1.10E-03	3.71E-03	Not Detected
4th week	1.68E-03	1.59E-03	5.44E-03	Not Detected
December 2016				
1st week	1.78E-03	1.02E-03	3.34E-03	Not Detected
2nd week	7.56E-04	1.06E-03	3.54E-03	Not Detected
3rd week	-8.64E-04	1.00E-03	3.39E-03	Not Detected
4th week	4.76E-04	7.20E-04	2.39E-03	Not Detected

Table 2-19: Weekly Activity concentrations of ^{60}Co (Bq/m^3) in Station A (Pre-HEPA) filters in 2016

Sample Date	^{60}Co Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
January 2016				
1st week	-1.22E-04	8.55E-05	2.92E-04	Not Detected
2nd week	2.71E-05	8.26E-05	2.76E-04	Not Detected
3rd week	-3.71E-05	8.28E-05	2.80E-04	Not Detected
4th week	-3.31E-05	5.66E-05	1.92E-04	Not Detected
February 2016				
1st week	-1.98E-05	8.43E-05	2.84E-04	Not Detected
2nd week	-1.41E-04	8.73E-05	2.98E-04	Not Detected
3rd week	-1.69E-04	1.10E-04	3.77E-04	Not Detected
4th week	-3.66E-05	7.27E-05	2.46E-04	Not Detected
March 2016				
1st week	9.04E-06	8.19E-05	2.74E-04	Not Detected
2nd week	-3.02E-05	8.33E-05	2.81E-04	Not Detected
3rd week	-1.15E-04	8.88E-05	3.03E-04	Not Detected
4th week	-5.40E-05	5.76E-05	1.96E-04	Not Detected
April 2016				
1st week	-1.64E-05	8.55E-05	2.88E-04	Not Detected
2nd week	-4.20E-05	8.46E-05	2.86E-04	Not Detected
3rd week	9.16E-05	8.56E-05	2.84E-04	Not Detected
4th week	-1.53E-05	6.56E-05	2.21E-04	Not Detected
May 2016				
1st week	-5.74E-05	8.37E-05	2.83E-04	Not Detected
2nd week	-1.07E-05	6.75E-05	2.25E-04	Not Detected
3rd week	6.25E-05	8.51E-05	2.83E-04	Not Detected
4th week	-5.71E-05	6.12E-05	2.07E-04	Not Detected
June 2016				
1st week	7.11E-05	8.23E-05	2.74E-04	Not Detected
2nd week	-1.08E-05	8.36E-05	2.81E-04	Not Detected
3rd week	-3.65E-05	8.16E-05	2.76E-04	Not Detected
4th week	4.34E-06	6.85E-05	2.30E-04	Not Detected
July 2016				
1st week	-2.77E-05	9.25E-05	3.11E-04	Not Detected
2nd week	-6.16E-05	9.50E-05	3.21E-04	Not Detected
3rd week	-4.81E-05	9.94E-05	3.35E-04	Not Detected
4th week	-2.80E-05	7.34E-05	2.47E-04	Not Detected

Table 2-19: Weekly Activity concentrations of ^{60}Co (Bq/m^3) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	^{60}Co Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
August 2016				
1st week	1.94E-05	8.48E-05	2.84E-04	Not Detected
2nd week	-4.57E-05	8.35E-05	2.82E-04	Not Detected
3rd week	-1.16E-04	1.22E-04	4.14E-04	Not Detected
4th week	-6.04E-05	6.78E-05	2.30E-04	Not Detected
September 2016				
1st week	-6.21E-05	8.48E-05	2.87E-04	Not Detected
2nd week	-4.52E-05	8.31E-05	2.81E-04	Not Detected
3rd week	-1.56E-04	9.09E-05	3.11E-04	Not Detected
4th week	4.80E-05	6.54E-05	2.17E-04	Not Detected
October 2016				
1st week	3.17E-05	8.44E-05	2.82E-04	Not Detected
2nd week	9.13E-05	8.21E-05	2.72E-04	Not Detected
3rd week	-6.78E-05	1.99E-04	6.73E-04	Not Detected
4th week	-7.58E-05	5.93E-05	2.02E-04	Not Detected
November 2016				
1st week	-6.90E-05	8.30E-05	2.81E-04	Not Detected
2nd week	2.66E-05	8.31E-05	2.80E-04	Not Detected
3rd week	1.28E-04	9.10E-05	3.10E-04	Not Detected
4th week	4.64E-05	1.48E-04	5.01E-04	Not Detected
December 2016				
1st week	9.86E-05	8.17E-05	2.70E-04	Not Detected
2nd week	-8.40E-05	9.07E-05	3.07E-04	Not Detected
3rd week	-8.92E-05	8.70E-05	2.95E-04	Not Detected
4th week	-4.96E-05	6.23E-05	2.11E-04	Not Detected

Table 2-20: Weekly Activity density of ^{137}Cs (Bq/g) in Station A (Pre-HEPA) filters in 2016

Sample Date	^{137}Cs Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
January 2016				
1st week	-1.94E-02	8.57E-01	2.86E+00	Not Detected
2nd week	2.06E+00	8.41E-01	2.75E+00	Not Detected
3rd week	-9.33E-02	1.14E+00	3.82E+00	Not Detected
4th week	-1.10E-01	5.84E-01	1.95E+00	Not Detected
February 2016				
1st week	1.04E+00	7.66E-01	2.53E+00	Not Detected
2nd week	7.18E-01	1.10E+00	3.64E+00	Not Detected
3rd week	4.10E-01	1.34E+00	4.47E+00	Not Detected
4th week	3.92E-01	1.46E+00	4.87E+00	Not Detected
March 2016				
1st week	-1.38E+00	1.29E+00	4.35E+00	Not Detected
2nd week	4.72E+00	3.45E+00	1.14E+01	Not Detected
3rd week	-1.06E+00	1.14E+00	3.84E+00	Not Detected
4th week	-3.06E-02	7.01E-01	2.34E+00	Not Detected
April 2016				
1st week	1.31E-01	1.03E+00	3.44E+00	Not Detected
2nd week	1.91E+00	1.08E+00	3.56E+00	Not Detected
3rd week	1.21E+00	1.09E+00	3.60E+00	Not Detected
4th week	2.48E+00	1.09E+00	3.57E+00	Not Detected
May 2016				
1st week	6.60E-01	1.31E+00	4.35E+00	Not Detected
2nd week	-6.62E-01	6.79E-01	2.26E+00	Not Detected
3rd week	-2.12E+00	1.35E+00	4.53E+00	Not Detected
4th week	-5.24E-01	6.42E-01	2.15E+00	Not Detected
June 2016				
1st week	7.49E-02	7.68E-01	2.56E+00	Not Detected
2nd week	1.61E+00	1.13E+00	3.74E+00	Not Detected
3rd week	7.30E-02	9.08E-01	3.03E+00	Not Detected
4th week	6.10E-01	5.58E-01	1.84E+00	Not Detected
July 2016				
1st week	7.41E-01	1.30E+00	4.30E+00	Not Detected
2nd week	1.36E+00	7.73E-01	2.54E+00	Not Detected
3rd week	8.59E-01	7.71E-01	2.55E+00	Not Detected
4th week	3.33E-01	5.36E-01	1.78E+00	Not Detected

Table 2-20: Weekly Activity density of ^{137}Cs (Bq/g) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	^{137}Cs Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
August 2016				
1st week	2.85E-01	4.65E-01	1.54E+00	Not Detected
2nd week	8.10E-01	6.07E+00	2.03E+01	Not Detected
3rd week	4.23E+00	8.64E+00	2.88E+01	Not Detected
4th week	3.48E+00	7.43E+00	2.48E+01	Not Detected
September 2016				
1st week	-6.69E-02	6.87E-01	2.30E+00	Not Detected
2nd week	-4.21E-01	1.17E+00	3.90E+00	Not Detected
3rd week	3.51E-01	9.71E-01	3.23E+00	Not Detected
4th week	-1.65E+00	9.72E-01	3.27E+00	Not Detected
October 2016				
1st week	-3.54E-01	9.76E-01	3.27E+00	Not Detected
2nd week	-8.37E-02	1.32E+00	4.40E+00	Not Detected
3rd week	2.22E+00	1.98E+00	6.54E+00	Not Detected
4th week	8.98E-02	4.79E-01	1.60E+00	Not Detected
November 2016				
1st week	-1.39E-01	1.05E+00	3.52E+00	Not Detected
2nd week	4.11E-01	7.56E-01	2.52E+00	Not Detected
3rd week	4.80E-01	5.29E-01	1.75E+00	Not Detected
4th week	2.76E-01	9.76E-01	3.27E+00	Not Detected
December 2016				
1st week	-6.58E-01	5.77E-01	1.94E+00	Not Detected
2nd week	7.55E-01	5.77E-01	1.90E+00	Not Detected
3rd week	-3.32E-01	5.56E-01	1.87E+00	Not Detected
4th week	3.32E-01	5.14E-01	1.71E+00	Not Detected

Table 2-21: Weekly Activity density of ^{40}K (Bq/g) in Station A (Pre-HEPA) filters in 2016

Sample Date	^{40}K Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
January 2016				
1st week	-8.00E+00	1.06E+01	3.58E+01	Not Detected
2nd week	-1.01E+01	1.04E+01	3.51E+01	Not Detected
3rd week	-9.55E+00	1.42E+01	4.78E+01	Not Detected
4th week	-3.01E+00	7.19E+00	2.42E+01	Not Detected
February 2016				
1st week	-5.46E+00	9.24E+00	3.14E+01	Not Detected
2nd week	1.17E+01	1.36E+01	4.51E+01	Not Detected
3rd week	-2.19E+00	1.43E+00	4.89E+00	Not Detected
4th week	1.83E+01	1.66E+01	5.51E+01	Not Detected
March 2016				
1st week	2.20E+01	1.48E+01	4.26E+00	Not Detected
2nd week	-1.69E+00	4.12E+01	1.38E+02	Not Detected
3rd week	-2.73E+00	1.35E+01	4.55E+01	Not Detected
4th week	-3.04E+00	8.47E+00	2.85E+01	Not Detected
April 2016				
1st week	-2.28E+01	1.36E+01	4.63E+01	Not Detected
2nd week	-5.26E+00	1.35E+01	4.55E+01	Not Detected
3rd week	1.39E+01	1.28E+01	4.22E+01	Not Detected
4th week	7.61E+00	1.34E+01	4.47E+01	Not Detected
May 2016				
1st week	-1.53E+01	1.35E+01	4.57E+01	Not Detected
2nd week	-4.34E+00	7.16E+00	2.39E+01	Not Detected
3rd week	-4.73E+00	1.30E+01	4.36E+01	Not Detected
4th week	-3.27E+00	6.31E+00	2.12E+01	Not Detected
June 2016				
1st week	1.14E+01	9.05E+00	2.99E+01	Not Detected
2nd week	-1.62E+00	1.37E+01	4.61E+01	Not Detected
3rd week	-3.50E+00	1.11E+01	3.73E+01	Not Detected
4th week	-3.47E+00	6.64E+00	2.24E+01	Not Detected
July 2016				
1st week	-6.58E+00	1.29E+01	4.35E+01	Not Detected
2nd week	-2.76E+00	7.89E+00	2.65E+01	Not Detected
3rd week	-5.00E+00	9.73E+00	3.28E+01	Not Detected
4th week	-2.90E+00	6.75E+00	2.27E+01	Not Detected

Table 2-21: Weekly Activity density of ^{40}K (Bq/g) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	^{40}K Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
August 2016				
1st week	1.05E+01	5.63E+00	1.85E+01	Not Detected
2nd week	8.10E-01	6.07E+00	2.03E+01	Not Detected
3rd week	4.23E+00	8.64E+00	2.88E+01	Not Detected
4th week	3.48E+00	7.43E+00	2.48E+01	Not Detected
September 2016				
1st week	-1.14E+01	8.53E+00	2.90E+01	Not Detected
2nd week	-2.01E-02	1.16E+01	3.88E+01	Not Detected
3rd week	-7.98E+00	1.21E+00	4.09E+01	Not Detected
4th week	-4.62E+00	9.38E+00	3.16E+01	Not Detected
October 2016				
1st week	5.27E+00	1.17E+01	3.89E+01	Not Detected
2nd week	7.55E+00	1.26E+01	4.18E+01	Not Detected
3rd week	-5.15E+00	2.00E+01	6.78E+01	Not Detected
4th week	2.02E+00	5.76E+00	1.92E+01	Not Detected
November 2016				
1st week	1.28E+01	1.22E+01	4.05E+01	Not Detected
2nd week	3.77E+00	9.06E-01	3.03E+01	Not Detected
3rd week	3.79E+00	5.54E+00	1.87E+01	Not Detected
4th week	1.06E+01	1.00E+01	3.43E+01	Not Detected
December 2016				
1st week	1.18E+01	6.70E+00	2.20E+01	Not Detected
2nd week	4.04E+00	5.69E+00	1.89E+01	Not Detected
3rd week	-5.74E+00	6.64E+00	2.25E+01	Not Detected
4th week	3.28E+00	4.96E+00	1.65E+01	Not Detected

Table 2-22: Weekly Activity density of ^{60}Co (Bq/g) in Station A (Pre-HEPA) Filters in 2016

Sample Date	^{60}Co Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
January 2016				
1st week	-1.22E+00	8.56E-01	2.92E+00	Not Detected
2nd week	2.79E-01	8.50E-01	2.84E+00	Not Detected
3rd week	-5.20E-01	1.16E+00	3.92E+00	Not Detected
4th week	-3.42E-01	5.85E-01	1.98E+00	Not Detected
February 2016				
1st week	-1.82E-01	7.74E-01	2.60E+00	Not Detected
2nd week	-1.93E+00	1.19E+00	4.07E+00	Not Detected
3rd week	-2.19E+00	1.43E+00	4.89E+00	Not Detected
4th week	-7.42E-01	1.47E+00	4.98E+00	Not Detected
March 2016				
1st week	1.40E-01	1.27E+00	4.26E+00	Not Detected
2nd week	-1.29E+00	3.55E+00	1.20E+01	Not Detected
3rd week	-1.47E+00	1.13E+00	3.87E+00	Not Detected
4th week	-6.50E-01	6.94E-01	2.36E+00	Not Detected
April 2016				
1st week	-1.97E-01	1.02E+00	3.45E+00	Not Detected
2nd week	-5.66E-01	1.14E+00	3.85E+00	Not Detected
3rd week	1.16E+00	1.08E+00	3.59E+00	Not Detected
4th week	-2.67E-01	1.15E+00	3.86E+00	Not Detected
May 2016				
1st week	-7.21E-01	1.05E+00	3.56E+00	Not Detected
2nd week	-9.48E-02	5.98E-01	2.00E+00	Not Detected
3rd week	7.65E-01	1.04E+00	3.46E+00	Not Detected
4th week	-4.79E-01	5.14E-01	1.74E+00	Not Detected
June 2016				
1st week	6.63E-01	7.68E-01	2.55E+00	Not Detected
2nd week	-1.49E-01	1.16E+00	3.89E+00	Not Detected
3rd week	-3.90E-01	8.72E-01	2.95E+00	Not Detected
4th week	3.55E-02	5.61E-01	1.88E+00	Not Detected
July 2016				
1st week	-3.23E-01	1.08E+00	3.64E+00	Not Detected
2nd week	-4.01E-01	6.19E-01	2.09E+00	Not Detected
3rd week	-3.91E-01	8.08E-01	2.73E+00	Not Detected
4th week	-2.13E-01	5.58E-01	1.88E+00	Not Detected

Table 2-22: Weekly Activity concentrations of ^{60}Co (Bq/g) in Station A (Pre-HEPA) filters in 2016 (continued)

Sample Date	^{60}Co Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
August 2016				
1st week	1.07E-01	4.67E-01	1.57E+00	Not Detected
2nd week	-2.86E-01	5.22E-01	1.77E+00	Not Detected
3rd week	-7.03E-01	7.38E-01	2.51E+00	Not Detected
4th week	-5.78E-01	6.49E-01	2.20E+00	Not Detected
September 2016				
1st week	-5.19E-01	7.09E-01	2.40E+00	Not Detected
2nd week	-5.05E-01	9.27E-01	3.13E+00	Not Detected
3rd week	-1.78E+00	1.03E+00	3.53E+00	Not Detected
4th week	5.52E-01	7.52E-01	2.50E+00	Not Detected
October 2016				
1st week	3.70E-01	9.85E-01	3.29E+00	Not Detected
2nd week	1.11E+00	9.95E-01	3.29E+00	Not Detected
3rd week	-6.68E-01	1.96E+00	6.63E+00	Not Detected
4th week	-6.31E-01	4.94E-01	1.68E+00	Not Detected
November 2016				
1st week	-9.09E-01	1.09E+00	3.71E+00	Not Detected
2nd week	2.47E-01	7.71E-01	2.60E+00	Not Detected
3rd week	6.46E-01	4.58E-01	1.56E+00	Not Detected
4th week	2.92E-01	9.35E-01	3.16E+00	Not Detected
December 2016				
1st week	6.50E-01	5.38E-01	1.78E+00	Not Detected
2nd week	-4.50E-01	4.85E-01	1.64E+00	Not Detected
3rd week	-5.92E-01	5.77E-01	1.96E+00	Not Detected
4th week	-3.42E-01	4.29E-01	1.45E+00	Not Detected

Table 2-23: Monthly Activity concentrations of ^{137}Cs (Bq/m^3) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	Activity Bq/m^3	Unc.(2σ) Bq/m^3	MDC Bq/m^3	Status
^{137}Cs	January	1.71E-05	2.27E-05	7.50E-05	Not Detected
	February	1.91E-05	2.55E-05	8.44E-05	Not Detected
	March	1.27E-06	1.81E-05	6.04E-05	Not Detected
	April	1.49E-05	1.83E-05	6.07E-05	Not Detected
	May	-1.30E-05	2.37E-05	7.91E-05	Not Detected
	June	6.69E-06	2.40E-05	7.95E-05	Not Detected
	July	6.19E-06	2.26E-05	7.53E-05	Not Detected
	August	3.63E-08	2.51E-05	8.37E-05	Not Detected
	September	2.94E-05	2.27E-05	7.50E-05	Not Detected
	October	3.33E-05	2.21E-05	7.26E-05	Not Detected
	November	7.64E-06	1.92E-05	6.42E-05	Not Detected
	December	8.49E-07	1.83E-05	6.12E-05	Not Detected

Table 2-24: Monthly Activity concentrations of ^{40}K (Bq/m^3) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	Activity Bq/m^3	Unc.(2σ) Bq/m^3	MDC Bq/m^3	Status
^{40}K	January	-1.79E-04	2.28E-04	7.70E-04	Not Detected
	February	9.28E-05	2.50E-04	8.33E-04	Not Detected
	March	3.08E-05	2.16E-04	7.25E-04	Not Detected
	April	-1.19E-05	2.28E-04	7.64E-04	Not Detected
	May	1.11E-04	2.17E-04	7.24E-04	Not Detected
	June	4.79E-04	2.24E-04	7.28E-04	Not Detected
	July	1.92E-04	2.19E-04	7.26E-04	Not Detected
	August	-9.98E-05	2.58E-04	8.68E-04	Not Detected
	September	2.24E-04	2.29E-04	7.59E-04	Not Detected
	October	4.71E-05	2.34E-04	7.85E-04	Not Detected
	November	2.03E-04	2.28E-04	7.56E-04	Not Detected
	December	1.29E-04	2.19E-04	7.30E-04	Not Detected

Table 2-25: Monthly Activity concentrations of ^{60}Co (Bq/m^3) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	Activity Bq/m^3	Unc.(2σ) Bq/m^3	MDC Bq/m^3	Status
^{60}Co	January	1.01E-05	1.86E-05	6.20E-05	Not Detected
	February	-2.79E-05	2.17E-05	7.37E-05	Not Detected
	March	-3.77E-05	1.84E-05	6.34E-05	Not Detected
	April	-3.35E-06	1.94E-05	6.49E-05	Not Detected
	May	3.04E-06	1.88E-05	6.31E-05	Not Detected
	June	-1.68E-05	1.95E-05	6.62E-05	Not Detected
	July	-1.66E-05	1.88E-05	6.38E-05	Not Detected
	August	-7.19E-07	2.14E-05	7.19E-05	Not Detected
	September	1.06E-05	1.90E-05	6.33E-05	Not Detected
	October	8.21E-06	1.91E-05	6.37E-05	Not Detected
	November	2.70E-05	2.02E-05	6.87E-05	Not Detected
	December	1.84E-05	1.74E-05	5.78E-05	Not Detected

Table 2-26: Monthly Activity density of ^{137}Cs (Bq/g) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	Activity Bq/g	Unc.(2σ) Bq/g	MDC Bq/g	Status
^{137}Cs	January	2.41E+00	3.19E+00	1.06E+01	Not Detected
	February	5.23E+00	6.97E+00	2.31E+01	Not Detected
	March	2.06E-01	2.93E+00	9.76E+00	Not Detected
	April	2.33E+00	2.87E+00	9.51E+00	Not Detected
	May	-1.39E+00	2.53E+00	8.46E+00	Not Detected
	June	9.85E-01	3.53E+00	1.17E+01	Not Detected
	July	8.43E-01	3.09E+00	1.03E+01	Not Detected
	August	3.24E-03	2.24E+00	7.47E+00	Not Detected
	September	1.15E+01	8.87E+00	2.92E+01	Not Detected
	October	4.24E+00	2.81E+00	9.26E+00	Not Detected
	November	8.53E-01	2.14E+00	7.17E+00	Not Detected
	December	1.73E-01	3.73E+00	1.24E+01	Not Detected

Table 2-27: Monthly Activity density of ^{40}K (Bq/g) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	Activity Bq/g	Unc.(2σ) Bq/g	MDC Bq/g	Status
^{40}K	January	-2.53E+01	3.22E+01	1.09E+02	Not Detected
	February	2.54E+01	6.83E+01	2.28E+02	Not Detected
	March	4.99E+00	3.50E+01	1.17E+02	Not Detected
	April	-1.86E+00	3.57E+01	1.20E+02	Not Detected
	May	1.18E+01	2.32E+01	7.74E+01	Not Detected
	June	7.05E+01	3.30E+01	1.07E+02	Not Detected
	July	2.61E+01	2.99E+01	9.90E+01	Not Detected
	August	-8.91E+00	2.31E+01	7.75E+01	Not Detected
	September	8.74E+01	8.94E+01	2.96E+02	Not Detected
	October	6.00E+00	2.98E+01	1.00E+02	Not Detected
	November	2.26E+01	2.54E+01	8.44E+01	Not Detected
	December	2.62E+01	4.45E+01	1.48E+02	Not Detected

Table 2-28: Monthly Activity density of ^{60}Co (Bq/g) in Station B (Post-HEPA) filters in 2016

Radionuclides	Sample Date	Activity Bq/g	Unc.(2σ) Bq/g	MDC Bq/g	Status
^{60}Co	January	1.42E+00	2.62E+00	8.74E+00	Not Detected
	February	-7.64E+00	5.93E+00	2.02E+01	Not Detected
	March	-6.10E+00	2.98E+00	1.03E+01	Not Detected
	April	-5.24E-01	3.04E+00	1.02E+01	Not Detected
	May	3.25E-01	2.01E+00	6.74E+00	Not Detected
	June	-2.47E+00	2.88E+00	9.74E+00	Not Detected
	July	-2.26E+00	2.57E+00	8.70E+00	Not Detected
	August	-6.42E-02	1.91E+00	6.42E+00	Not Detected
	September	4.13E+00	7.41E+00	2.47E+01	Not Detected
	October	1.05E+00	2.43E+00	8.12E+00	Not Detected
	November	3.02E+00	2.26E+00	7.68E+00	Not Detected
	December	3.74E+00	3.55E+00	1.18E+01	Not Detected

Non-Radiological Monitoring

The CEMRC has historically measured WIPP underground exhaust air for metals; however, following the February 14, 2014 underground radiation release event, all metals analyses ceased as the CEMRC went into an emergency mode whereby all filters were transferred directly to the Radiochemical Group for immediate processing. Since elevated levels of radioactive materials were detected on the FAS filters periodically after the 2014 event, metals analysis was suspended for the remainder of the 2014 year. Metals analysis on the FAS filters resumed in January of 2015. The results reported herein are for Station B.

Sample Preparation and Analysis

All analyses of the FAS filters are performed according to the methods detailed in the CEMRC document-controlled, standard operating procedures.

Samples for metals analyses are prepared by acid digestion in a CEM MARS™ Xpress™ microwave unit according to CEMRC procedures. Individual FAS filters are placed in separate Teflon vessels and digested at 195°C using a dilute acid matrix consisting of nitric acid, hydrochloric acid, and hydrofluoric acids. A blank filter and Certified Reference Material (CRM) filter are also digested in the same manner for QC-purposes. All acids used in the digestions are either purchased as "trace metal" grade or purified in-house with a Milestone Inc. sub-boiling quartz distillation apparatus. After digestion, the FAS filter solutions are then combined into weekly composites and a small aliquot of each weekly composite is removed for inorganic analysis by Inductively-Coupled Plasma Mass Spectrometry (ICP-MS).

Elemental analysis by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) is conducted on weekly composites of the FAS filters using a low-resolution Perkin Elmer Elan DRC-e ICP-MS, which has a peak resolution of <0.71amu for the mass range reported. The mass calibration value is within 0.1amu of the published true values. The system is configured with a cyclonic spray chamber. Triplicate readings were performed on each digestate, with the average result reported. The ICP-MS analyses used at CEMRC can provide data for up to 35 elements in the FAS filters, but in practice the concentrations of some elements, including, but not limited to, As, Be, Cd, Er, Eu, Sc, Se, Sm, Tl and V are often below detectable or quantifiable levels. A second set of elements (notably Ag, Li, and Sn) often have variable concentrations in the blank filters which makes their quantification difficult.

Results and Discussion

Time-series plots from 2015 to 2016 showing the trace elemental data for Station B are exhibited in Figures 2-31 through 2-36. Only the following metals are reported herein: aluminum (Al), cadmium (Cd), magnesium (Mg), lead (Pb), thorium (Th), and uranium (U). Data presented in

these plots only reflect concentrations above MDC. The MDCs are re-calculated annually, and vary slightly from year to year. The concentrations of Cd, Th, and U regularly hover right around the MDC and for a month or two in 2015, concentrations for Cd and U never exceeded the MDC.

Previously, the CEMRC used WIPP underground exhaust samples collected from the Station A sampling probe; however, following the February 14, 2014 underground radiation release event, all samples collected for metal analysis have been taken from the Station B sampling probe which is sampling the WIPP underground exhaust air after HEPA filtration. As a result, the CEMRC has no historical studies for metals analysis on Station B filters prior to the 2014 WIPP underground radiation release event. The CEMRC's assumption is that the concentrations of metals measured on Station B filters post the 2014 WIPP underground radiation release event should be similar to Station A concentrations prior to the 2014 WIPP underground radiation release event. Better yet, a red line on each figure represents the average concentration measured on Station A filters prior to September 2000 when the WIPP received its first shipment of mixed waste. As expected, the metal concentrations for Al, Cd, Mg, Pb, Th, and U measured at Station B stayed well below pre-operational conditions observed on Station A filters. One exception occurred with Pb in July of 2015 (14.2 ng/m^3). However, this is well below the maximum pre-operational measurement for lead (45.6 ng/m^3) measured at Station A. For reference, the EPA primary standard (established limit to protect the public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly) for Pb in ambient air (150 ng/m^3) averaged over a rolling 3-month period (See Table 1).

Historical studies at Station A have shown that concentrations of hazardous metals and various trace elements can be highly variable over time, even in the samples collected prior to WIPP receiving the mixed waste in September 2000. Cadmium levels observed on Station B filters were no exception (Figure 2-33). Despite noticeable variations in cadmium measurements, all of these values are below the average pre-operational Station A values and well-below the Recommended Exposure Limit (REL) of 2000ng/m3 for Cd (See Table 1).

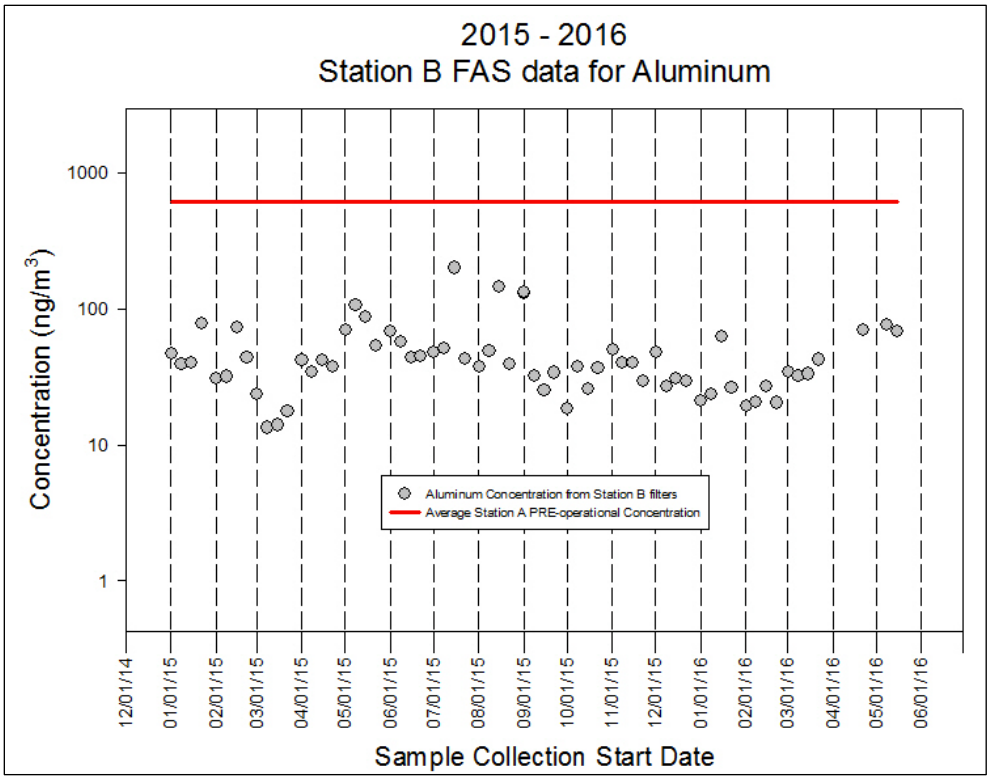


Figure 2-31: Concentrations of Aluminum in WIPP Exhaust Air, Station B, from 2015 to 2016 compared to pre-operational Station A concentrations.

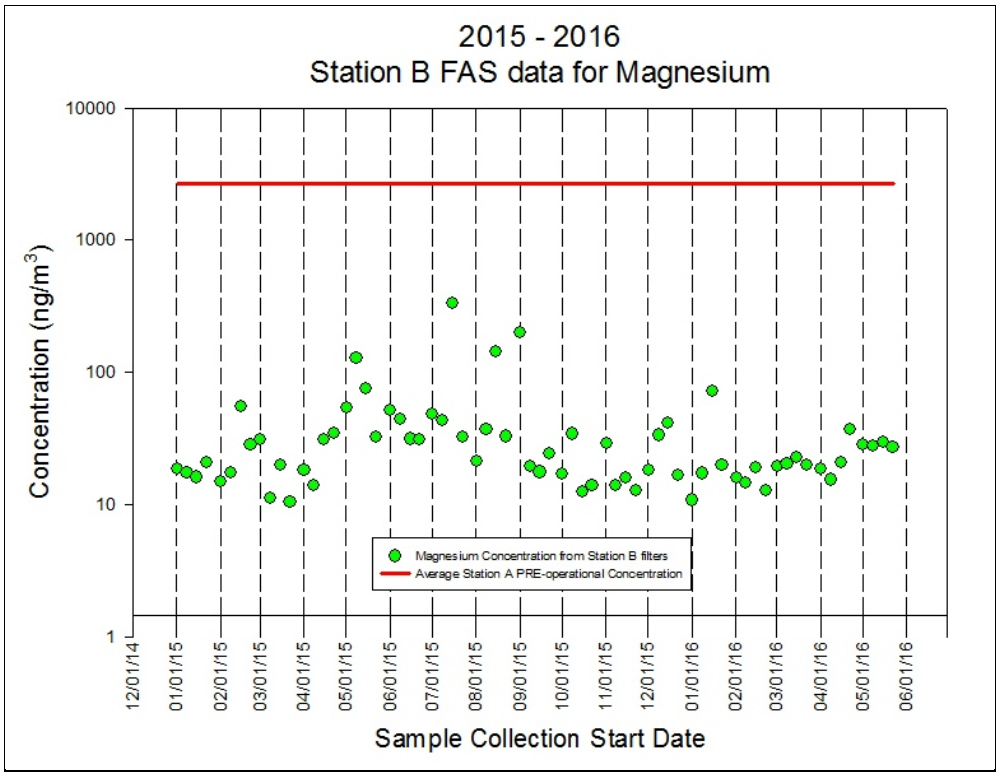


Figure 2-32: Concentrations of Magnesium in WIPP Exhaust Air, Station B, from 2015 to 2016 to pre-operational Station A concentrations

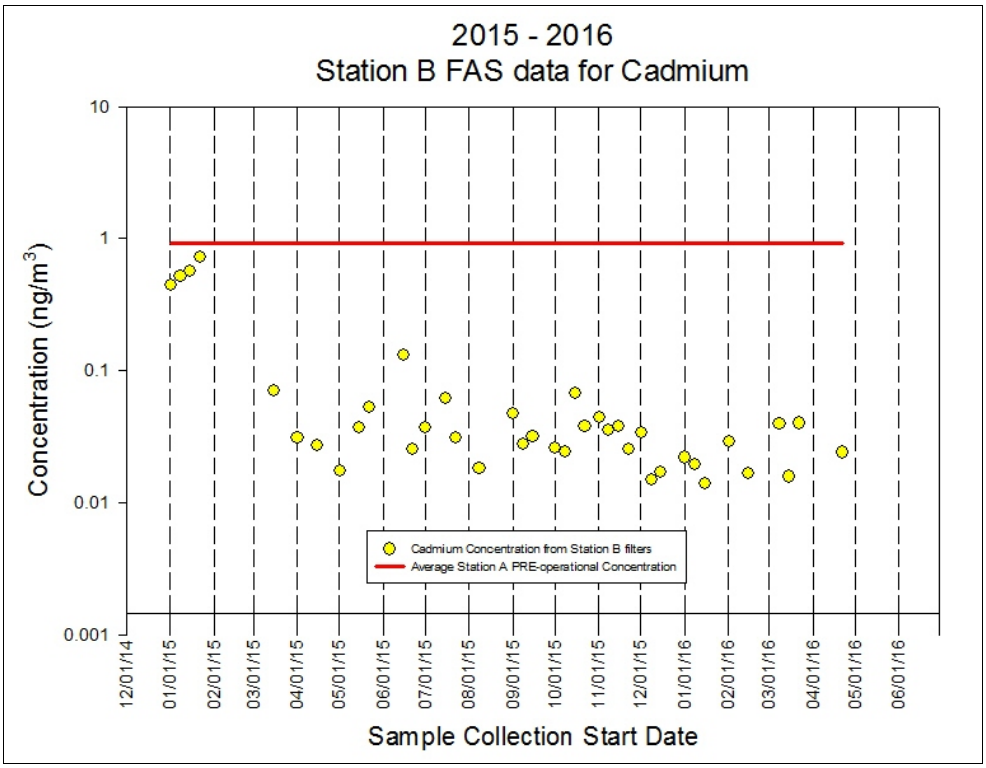


Figure 2-33: Concentrations of Cadmium in WIPP Exhaust Air, Station B, from 2015 to 2016 to pre-operational Station A concentrations

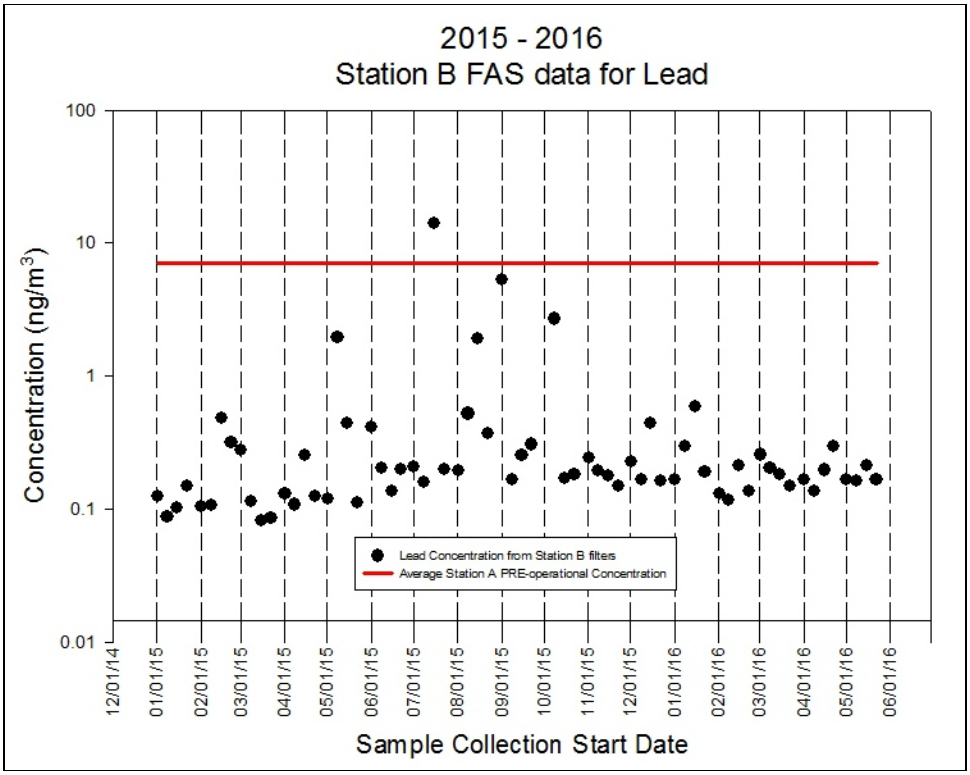


Figure 2-34: Concentrations of Lead in WIPP Exhaust Air, Station B, from 2015 to 2016 to pre-operational Station A concentrations

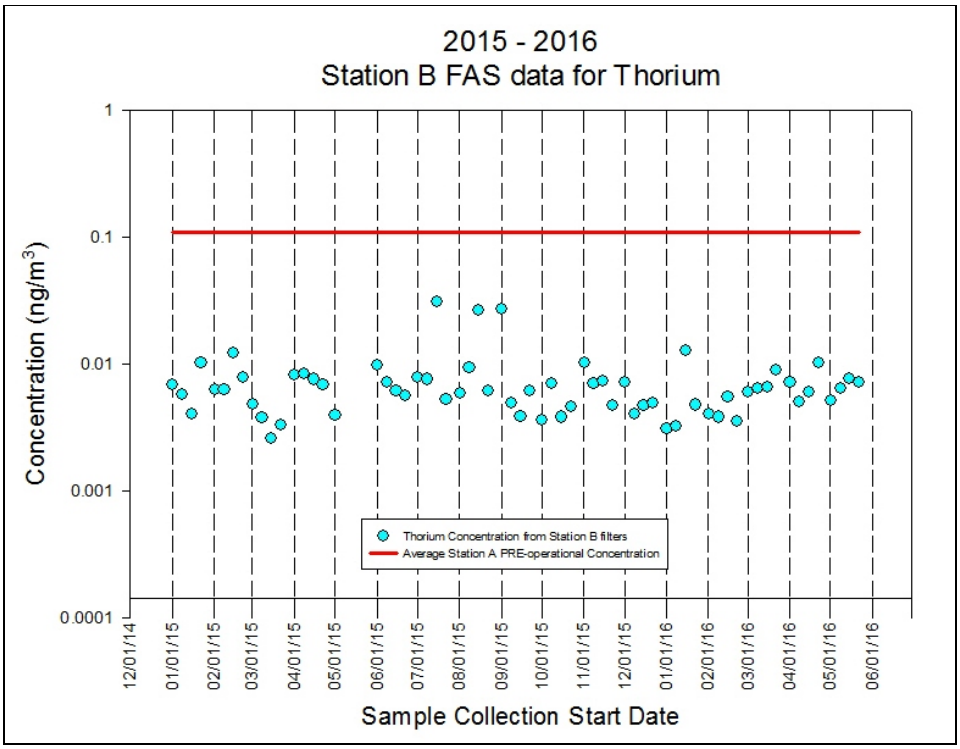


Figure 2-35: Concentrations of Th in WIPP Exhaust Air, Station B, from 2015 to 2016 to pre-operational Station A concentrations

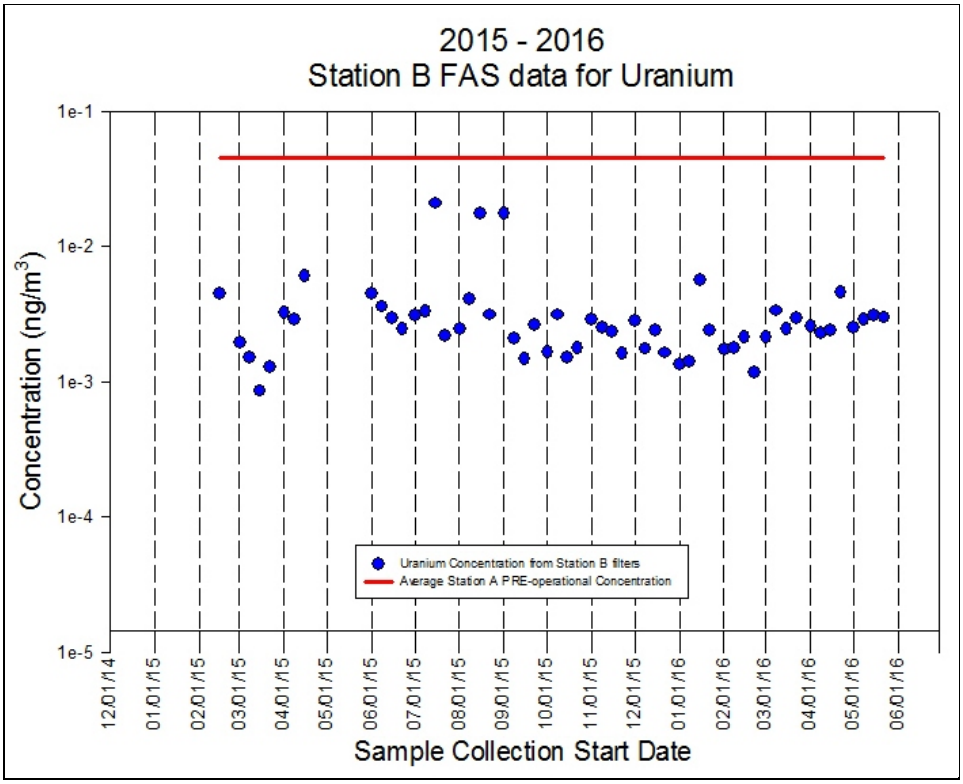


Figure 2-36: Concentrations of U in WIPP Exhaust Air, Station B from 2015 to 2016 to pre-operational Station A concentrations

Table 2:29: General Information about Inorganic Contaminants in Air

Contaminant	Limit	Sources of contaminants	Potential Health Effects from Long Term Exposure	Source
Aluminum (respirable fraction)	5mg/m^3 (8-hour time weighted average)	Dust, solder fumes	Pulmonary fibrosis	NIOSH Recommended Exposure Limit (REL)[2]
Cadmium (respirable dusts)	0.002mg/m^3	Burning fossil fuels, smoking, and incineration of municipal waste materials	Irritation/damage to lungs, kidney damage	EPA[3]
Magnesium	None	N/A	N/A	N/A
Lead (Pb)[1]	0.15µg/m^3	Dust, mining, smelting, refining activities	Neurological effects in children and cardiovascular effects in adults	EPA[4]
Thorium	None	Dust	N/A	EPA[5]
Uranium (insoluble and soluble compounds)	0.2mg/m^3	Dust, uranium mining	Chronic lung disease, cancer	NIOSH Recommended Exposure Limit (REL)[6]

[1] EPA limit is enforceable
[2] http://www.cdc.gov/niosh/npg/npgd0022.html ***and*** http://www.cdc.gov/niosh/npg/nengapdxg.html
[3] American Conference of Governmental Industrial Hygienists (ACGIH). *1999 TLVs and BEIs. Threshold Limit Values for Chemical Substances and Physical Agents. Biological Exposure Indices*. Cincinnati, OH. 1999. *and* http://www.epa.gov/ttn/atw/hlthef/cadmium.html
[4] http://www.epa.gov/superfund/lead/health.htm
[5] http://www.epa.gov/superfund/health/contaminants/radiation/pdfs/thorium.pdf
[6] National Institute for Occupational Safety and Health (NIOSH). *Pocket Guide to Chemical Hazards*. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention. Cincinnati, OH. 1997 *and* http://www.epa.gov/ttnatw01/hlthef/radionuc.html
[7] http://www.cescenter.com/documents/Regulatory%20Limits%20for%20Contaminants%20of%20Concern.pdf
[8] https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9992

CHAPTER 3

Ambient Air Monitoring

Ambient air monitoring essentially means the monitoring of "the air around us". Ambient air networks are an important part of a facility's environmental monitoring program. They monitor for both routine and unforeseen releases, provide verification that the facility is in compliance with the public radiological dose limit and are used to assess impact to the environment over time. Additionally, they can also provide a precautionary measure in the event of accidental releases of radioactivity. The overall effectiveness of an air-monitoring network is dependent on the number and placement of samplers, flow rates and sampling times of the samplers, and analytical methods used to measure radionuclides in air. The CEMRC operates a network of continuously operating samplers at three locations in the vicinity of the WIPP site to monitor radioactive constituents in the ambient air near the repository and two ambient air samplers in the two closest municipalities nearest the WIPP facility (the Village of Loving and the City of Carlsbad). The ambient air monitoring sites nearest the WIPP facility are located in the most prevalent wind directions from the facility, whereas the ambient air monitoring sites in Loving and Carlsbad are located on village of Loving owned property and at the CEMRC facility primarily as a matter of convenience and cost. The program is designed to detect radioactive materials in the air in case of an emergency response situation. The ambient air monitoring is an important aspect of the CEMRC environmental monitoring program that seeks to monitor the source of radionuclides in the WIPP environment, to detect any release of radioactive materials into the environment from the WIPP-related activities, and to ensure the protection of human and environmental health.

The radionuclides of greatest concern in the WIPP are $^{239+240}$Pu and ^{241}Am, which account for more than 99% of the total radioactivity slated for disposal within the repository. According to current estimates, the WIPP repository will contain approximately 1.20×104 kg of Pu isotopes and 203 kg of ^{241}Am (SOTERM-2014). In this context, the variation in concentrations of these radionuclides in the WIPP environment is important not only because they are the main components of the WIPP wastes, but also because of their global background activity. Transuranic elements are not naturally present in measurable quantities in the ambient air. With few exceptions, nuclear weapon testing was the main source of plutonium in ambient air, but the amount of plutonium still remaining in the atmosphere today from these tests is small because most of the radioactivity has been deposited on the ground as fallout (Harley 1980; Perkins and Thomas 1980). Since the first nuclear test detonation in New Mexico in 1945, approximately 11 PBq of $^{239+240}$Pu has been ejected into the atmosphere (Perkins and Thomas 1980; UNSCEAR, 2000). In addition 0.6 PBq of ^{238}Pu were released over the south Pacific in the high altitude destruction of the SNAP-9A satellite power source in 1964 (Hardy et al., 1973; Krey, 1968). Most

of the global fallout was deposited in the northern hemisphere and the majority of the fallout was deposited in the middle latitudes.

Currently, ^{238}Pu, ^{239}Pu and ^{240}Pu isotopes can be measured as traces in environmental samples, with a ^{238}Pu/$^{239+240}$Pu activity ratio of 0.03 at mean latitudes of 40o-50o N tracing their global origin (UNSCEAR, 2000). At present, almost all plutonium being introduced into the atmosphere can be found in the surface soil or oceans. Depending on meteorological conditions, physiochemical properties of soil, and human activity, plutonium can migrate vertically with various rates, can be transported into plants or can become re-suspended into the air with eroded soil particles. These aerosol particles can be trapped on a filter in an air monitoring station or subjected to wash-down from the atmosphere with precipitation (i.e. rainfall or snowfall). Air samples can thus give information about activity levels both in the air and soil of a particular area, and allow evaluation of seasonal variations of plutonium in the air.

Atmospheric concentration of Plutonium in the Northern Hemisphere

Plutonium is not naturally present in measurable quantities in the ambient air. With few exceptions, nuclear weapon testing was by far the main source of plutonium in ambient air, but the amount of plutonium still remaining in the atmosphere today from these tests is small because most of the radioactivity has been deposited on the ground as fallout (Lee et al., 1998). Concentrations of plutonium in surface air were not systematically monitored during 1959-1964 at the time of the heaviest contributions from global fallout. Because the ^{90}Sr global fallout pattern is similar to that of plutonium isotopes, with an average $^{239+240}$Pu to ^{90}Sr global activity ratio of about 0.025 (decay corrected to 2000) based on the normalized production rate for ^{90}Sr and plutonium isotopes in nuclear explosions (UNSCEAR, 2000). The $^{239+240}$Pu to ^{90}Sr ratio method (Bennett 1978) is generally utilized to make good estimates of the plutonium concentrations in air.

The current concentration of $^{239+240}$Pu in ambient air is about ~1000 times lower than levels measured during the early 1960s and 1970s. During these decades, plutonium concentrations in surface air were highly variable for a number of reasons such as continued contributions from weapons testing and the recycling of deposited plutonium back into the atmosphere via re-suspension of contaminant soil. Furthermore, the fallout radionuclides were not deposited evenly over the earth and are known to vary with latitude, being highest in the middle latitudes of the northern hemisphere. The measurement of soil inventories have shown that the weapons fallout tended to deposit in areas with abundant rainfall. This heterogeneity is due to the fact that wet deposition more effectively removed the radioactive particles from the atmosphere than dry deposition (Hardy et al., 1973). The Chernobyl accident in April 1986, which released about 70 TBq of the plutonium isotopes increased the concentration of $^{239+240}$Pu in surface air during 1986-1987, especially in Europe and contributed slightly to the plutonium global inventory (UNSCEAR 2000). However, following a peak in 1986, the concentrations of

$^{239+240}$Pu are shown to decrease continuously. In order to establish an environmental baseline of $^{239+240}$Pu deposition, time series data of plutonium are important as it provides information about the factors that control the past and present concentrations of plutonium in the atmosphere. Such data are also important in understanding the long-term history of plutonium in the environment.

While the current atmospheric plutonium data and those collected during the era of above ground nuclear weapons testing both show springtime peaks, the causes for the cycles are likely quite different. Studies conducted prior to the end of the atmospheric weapons testing showed that seasonal cycle of plutonium concentrations (highest in spring and lowest in summer) is associated with enhanced transport of radioactive aerosols from the stratosphere-to the troposphere. However, after the cessation of nuclear weapons testing in 1980 and with a comparatively small additional input from the Chernobyl, the most plutonium in the air today is associated with re-suspension soil which is contaminated from weapons fallout. As mentioned earlier, re-suspension is considered to be the predominant mechanism for maintaining the small residual plutonium in the surface air samples. The importance of re-suspension as a mechanism for recycling plutonium back into the atmosphere has been discussed in many publications (Rosner et al., 1997; Arimoto et al., 2005). The general discussion on transuranic re-suspension has been thoroughly reviewed by (Sehmel 1987). On the other hand, Nicholson 1988 has reviewed re-suspension of radionuclides including plutonium in contaminated areas, which are usually arid or semiarid regions. The re-suspension is dependent on current meteorological conditions. Windy, dry days can increase the soil re-suspension, whereas precipitation (rain or snow) can wash particulate matter out of the air and decreases rate of re-suspension.

An important finding of the earlier studies was that the activity of Pu and the concentration of Al in aerosols were correlated and this was driven by the resuspension of dust particles contaminated with radioactive fallout from past nuclear weapons tests. Similar results were found for Am and Al. Related studies of soils collected on and near the WIPP site have shown that correlations exist among Al and both naturally-occurring and bomb-derived radionuclides including $^{239+240}$Pu (Kirchner et al., 2002). Here we briefly review the methods used for the ambient aerosol studies and then summarize some recent results, highlighting the continuing efforts to evaluate potential releases from the WIPP.

Sampling Locations

At the CEMRC, ambient aerosols are collected using high volume samplers ("hivols," flow rate ~1.13 m^3 min^{-1}) from three monitoring stations: (1) Onsite, which is about 0.1 km northwest of the WIPP exhaust shaft; (2) Near Field, about 1 km northwest of the facility; and (3) Cactus Flats, about 19 km southeast of the WIPP site. The locations of the three ambient air sampling stations are depicted in Figure 3-1. The samplers are primarily located in the prevailing downwind direction and were selected based on an analysis of probable wind-direction and speed scenarios

in case of an accident involving a release of radioactivity during the operation of the WIPP. The aerosol samples were collected on 20×25 cm A/ETM glass fiber filters (Pall German Laboratory, Ann Arbor, MI, pore size 1µm). A typical sampling period lasts for about three to four weeks depending on the levels of particulate matter that accumulates on the filters. These samplers are operated to maximize particulate loading without impacting air flow, if flow volume drops down to (0.99 m^3/min) filters are changed. Filter change outs also occur in the event of a power outage or if a sampler stops due to some mechanical issue. Each filter is weighed before and after sampling to determine the weight of aerosol material collected on the filters. Actinide analyses were performed on each individual filter by the CEMRC. As shown in Figure 3-2, the sampling height of each aerosol station is ~5 m from the ground.

Following the underground radiation release event of 2014, the CEMRC added three additional high-volume sampling stations in order to provide additional information to area residents in the event of a future radiation release event. The new sampling stations are located in : (1) Carlsbad, behind the CEMRC facility, about 56 km northwest of the WIPP site; (2) on the south side of Loving, about 47 km southwest of the WIPP facility, and (3) on the east side of the WIPP facility near the WIPP meteorological station, about 0.3 km east of the WIPP facility. These sampling locations are shown in Figure 3-3. Aerosol samples are currently only collected from two sites (Loving and Carlsbad). The third high-volume sampling station located on the east side of the WIPP was not fully deployed until the summer of 2017.

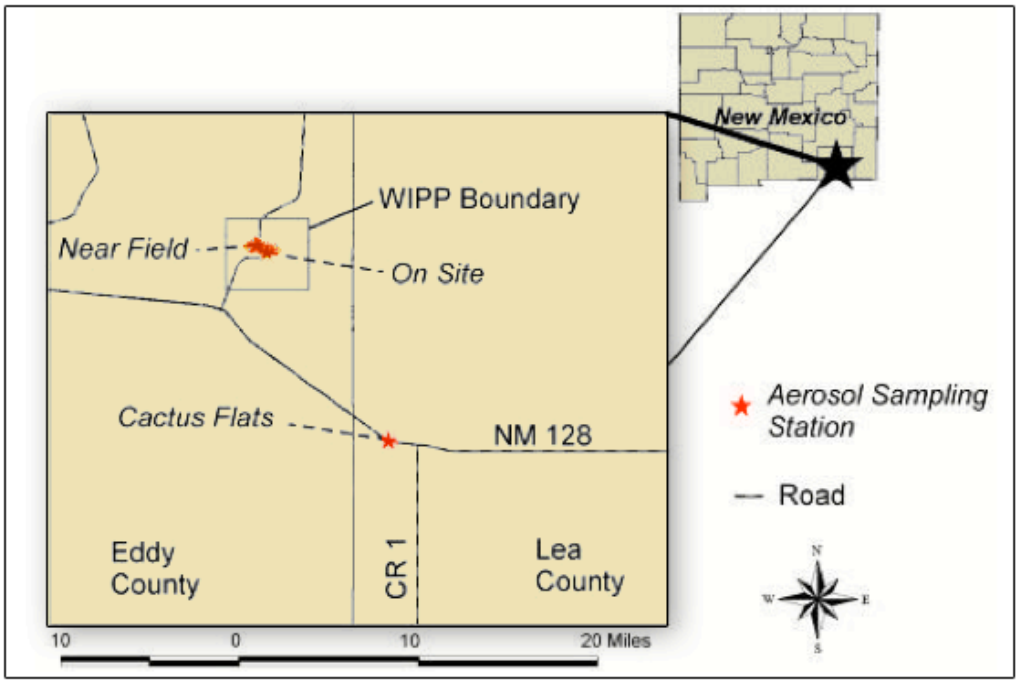


Figure 3-1: Ambient Aerosol Sampling Locations (Prior to Radiation Release 2014)

Figure 3-2: Typical WIPP Site High Volume Air Sampling Station

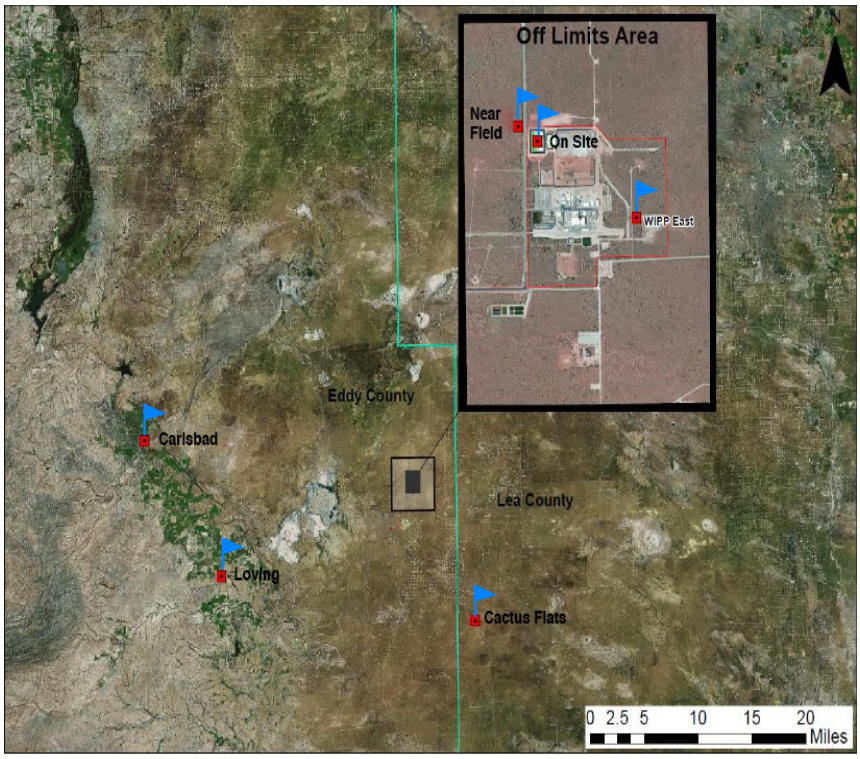


Figure 3-3: Ambient Aerosol Sampling Locations (Post Radiation Release)

Sample Preparation

The high-volume samples were analyzed for selected radionuclides, including ^{238}Pu, $^{239+240}$Pu, ^{241}Am and recently ^{235}U, ^{234}U and ^{238}U following 6 hours of heating in a muffle furnace at 500° C to drive off organics. Once heated in the muffle furnace, each filter was then digested with a strong acid mixture of HCl+HF+$HClO_4$, to aid in the complete decomposition of silica. Samples were then treated with conc. $HClO_4$ and HNO_3 for the removal of fluoride ions. The inside walls of the beaker were rinsed carefully with HNO_3 to gather residual HF and evaporation was repeated to ensure that all residual HF is removed from the matrix. The residues were then dissolved in 1.0 M HCl for subsequent radionuclide separation and analysis. The acid digestates of the filter composite samples were then split into two fractions. One fraction was analyzed by gamma spectroscopy for ^{40}K, ^{60}Co, and ^{137}Cs. The other fraction was analyzed for the actinides. The actinides are separated as a group by co-precipitation on $Fe(OH)_3$. Pu isotopes are separated and purified using a two-column anion exchange resin (Dowex1-× 8, Eichrom, 100-200 mesh), while TRU chromatography columns were used for the separation of Am. The samples were then micro-co-precipitated using an Nd-carrier, deposited onto filters, mounted on planchettes, and counted by Alpha spectroscopy for 5-days. Gamma-emitting nuclides in the air filters were measured using a high purity germanium detector, HpGe (Canberra) for 48 hours.

Data Reporting

The activities of the actinides and gamma radionuclides in the air samples are reported as activity concentration (Bq/m^3) and activity density (Bq/g). Activity concentration is calculated as the activity of radionuclides detected in Bequerels (Bq) divided by the volume of air in cubic meters, while activity density is calculated as the nuclides activity divided by the aerosol mass in grams collected on the filter.

Results and Discussion

CEMRC detected trace levels of ^{241}Am and $^{239+240}$Pu at two sampling locations (Onsite and Near Field) in February of 2014 immediately following the February 14, 2014 underground radiation release event at the WIPP. No radioactivity was detected at Cactus Flats Station located approximately 19 km southeast of the WIPP facility. The highest concentrations detected were 10.2 µBq/m^3 for $^{239+240}$Pu and 115.2 µBq/m^3 for ^{241}Am at the Onsite sampling Station, and 81.4 µBq/m^3 for ^{241}Am and 5.78 µBq/m^3 for $^{239+240}$Pu at the Near Field Station (shown in Figures 3-4 and 3-5). The levels detected were very low and localized, and no radiation-related health effects among local workers or the public are expected. The ^{241}Am to $^{239+240}$Pu ratios of the elevated airborne radioactive concentrations are generally consistent with the waste stream suspected to have been released at WIPP. A week after the event, the airborne radioactive particulate levels at these stations had decreased by a hundred times, and two weeks later, the levels at these stations were back to the pre-release levels and sometimes not even detectable, demonstrating no long-

term environmental impacts remain from the 2014 underground radiation release event at the WIPP.

The concentrations of $^{239+240}$Pu, ^{241}Am and ^{238}Pu measured in the ambient air filters during 2016 are listed in Tables 3-1 to 3-3 (Onsite Station), Tables 3-4 to 3-6 (Near Field Station) and Tables 3-7 to 3-9 (Cactus Flats Station). The ^{241}Am and $^{239+240}$Pu concentrations slightly above minimum detectable levels were detected in a few ambient air samples collected around WIPP in 2016 and are attributed to the resuspension of contaminated soil dust plus the local precipitation to some extent. Studies conducted prior to the end of the atmospheric weapons testing showed that Pu activities varied seasonally, being highest in spring and summer because of the springtime enhanced transportation of radioactive aerosols from the stratosphere to troposphere. However, with the cessation of nuclear weapons tests and considering the fact that the residence time of Pu in the atmosphere is on the order of a year, the stratospheric deposition of radionuclides, including Pu, is no longer a dominant factor for the Pu concentration in air. Additionally, the Chernobyl nuclear power plant accident that occurred in April 1986 did not bring significant amounts of Pu to this area. Therefore, re-suspension is assumed to be the main source of Pu in the aerosol samples around the WIPP.

The WIPP's historical ambient air monitoring data also indicate frequent detection of $^{239+240}$Pu and ^{241}Am in ambient air samples collected around WIPP (Figures 3-4 and 3-5). The detection of ^{238}Pu is relatively infrequent because this radionuclide is not primarily from weapons fallout, but was released by the burn-up of nuclear powered satellites such as SNAP-9A (Hardy et al., 1973, Harley 1980). Peaks in $^{239+240}$Pu and ^{241}Am activity concentrations in aerosol samples from the three study sites generally occur from March to June, which is when strong and gusty winds in the area frequently give rise to blowing dust. The observed seasonality in plutonium and americium activity concentrations in the WIPP environment is therefore attributable to the re-suspension of contaminated soil dust. In cases where ^{238}Pu was detected, its activity tended to increase with $^{239+240}$Pu, suggesting that the detected plutonium and americium isotopes are likely being re-suspended by wind and have an atomic-testing and satellite burn-up fallout origin.

Additionally, in the vicinity of WIPP there is a potential local source of anthropogenic (human-caused) radioactivity from an underground nuclear test that was part of the Plowshare project, the Gnome test (USAEC. 1973). The Gnome site is located about 8.8 km southwest of the WIPP site. In 1961 an underground test of a 3.3-kiloton ^{239}Pu device vented radioactive materials to the surface (USAEC. 1973, Faller, 1994). Clean-up efforts at this site have been carried out in several campaigns since that time, and the surface contamination is now well below any level of public health and environmental concern. However, low levels of ^{137}Cs and plutonium are still detectable in some surface soil samples collected from the Gnome site (CEMRC Annual Report, 2005/2006). The transport of these contaminants from the Gnome site to the WIPP remains a possibility during high wind seasons (Stout and Arimoto, 2010); however, more than fifteen years of monitoring data and the activity levels detected, as well as their atomic ratio measurements,

suggest that pre-release-event plutonium and americium in aerosol and soil samples collected near the WIPP facility primarily represent redistributed global fallout.

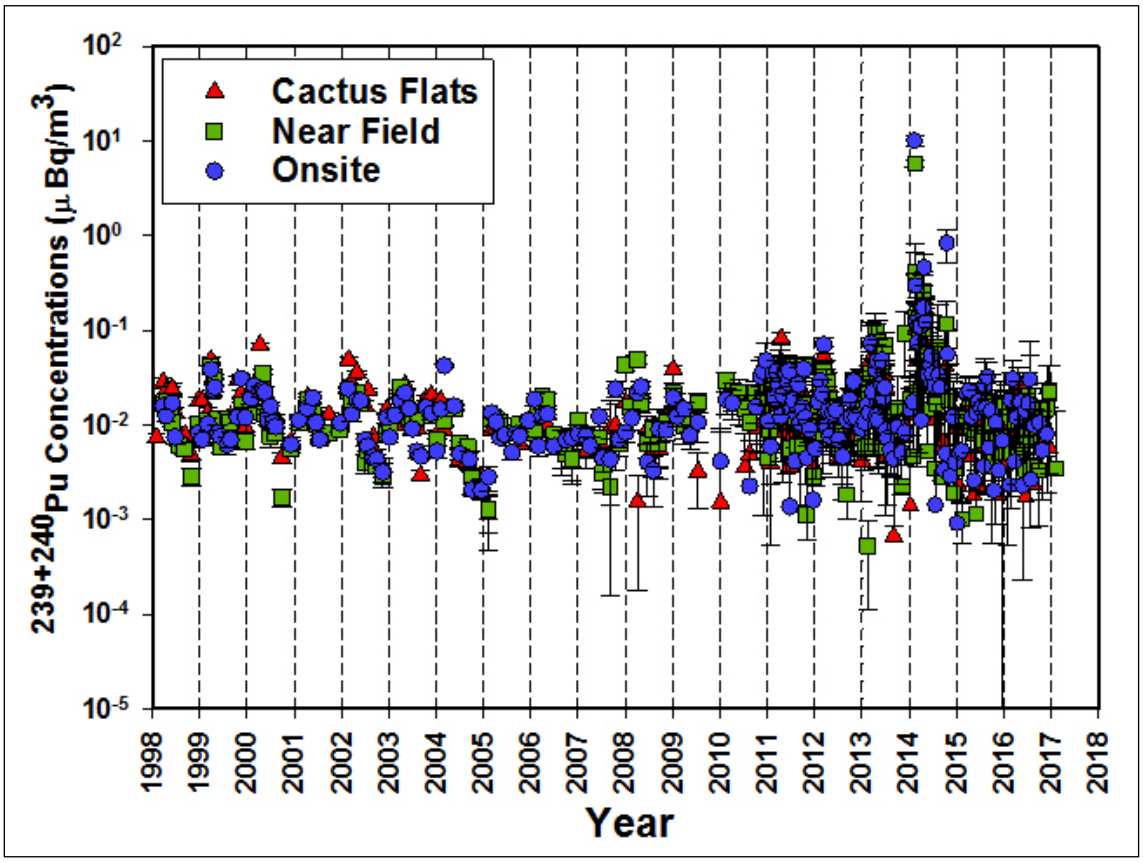


Figure 3-4: The Pre- and Post-radiological event $^{239+240}$Pu concentrations in ambient air at three stations in the vicinity of the WIPP site

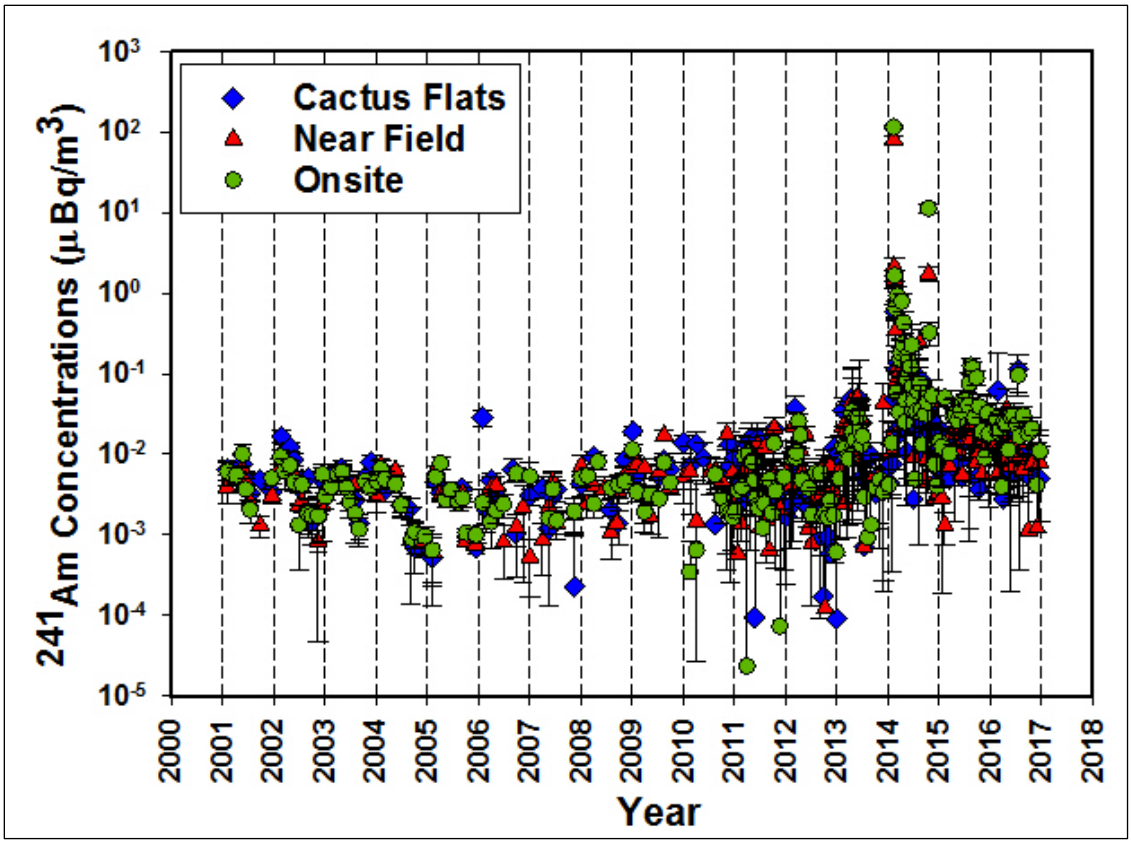


Figure 3-5: The Pre- and Post-radiological event ^{241}Am concentrations in ambient air at three stations in the vicinity of the WIPP site

The $^{239+240}$Pu activity densities (activity per unit mass aerosol collected) were in the range of 0.00-0.67 mBq/g at the Onsite station, 0.00-1.34 mBq/g at the Near Field station and 0.05-2.1 mBq/g at the Cactus Flats station, while that of ^{241}Am were in the range of 0.08-2.10 mBq/g at the Onsite station, 0.03-1.48 mBq/g at the Near Field station and 0.11-4.14 mBq/g at the Cactus Flats station. The aerosol mass loadings recorded in these sampling stations varied in the range from 0.5-1.70 g at Onsite, 0.3-1.70 g at Near Field and 0.1-1.53g at Cactus Flats. Furthermore, the mass loadings at all stations tend to track one another remarkably well as shown in Figures 3-6 and 3-7. The activity density of $^{239+240}$Pu, ^{241}Am and ^{238}Pu measured in the ambient air filters during 2016 are listed in Tables 3-10 to 3-12 (Onsite Station), Tables 3-13 to 3-15 (Near Field Station) and Tables 3-16 to 3-18 (Cactus Flats Station).

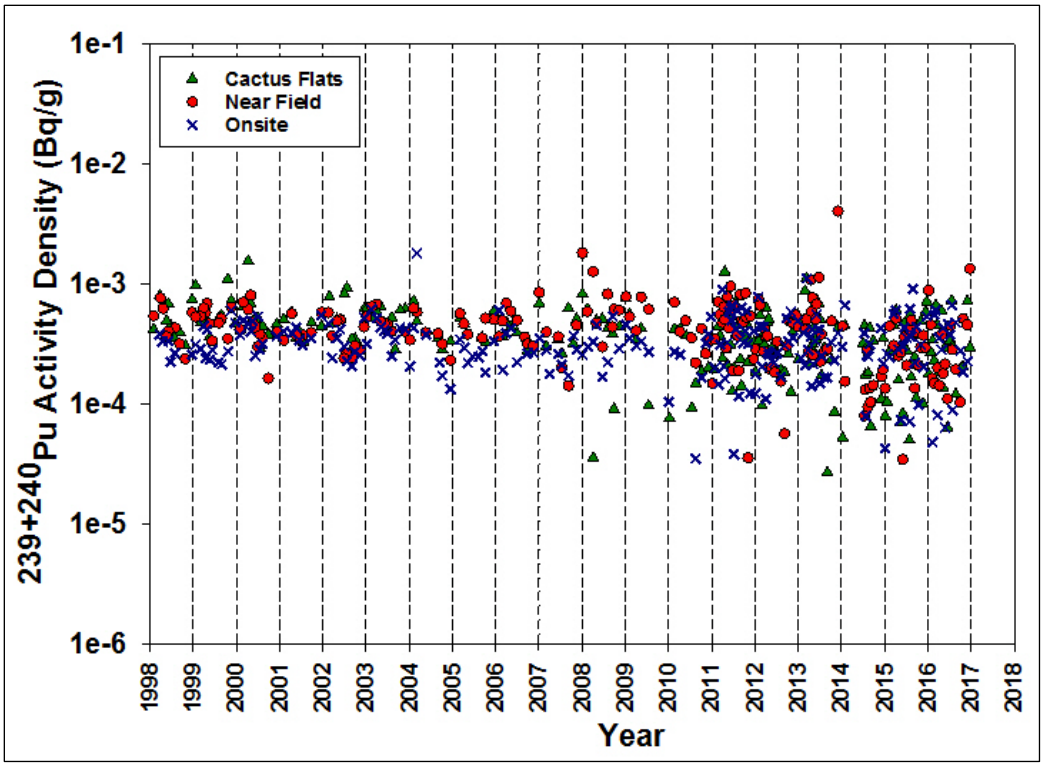


Figure 3-6: The Pre- and Post-radiological event $^{239+240}$Pu densities in ambient air at three stations in the vicinity of the WIPP site

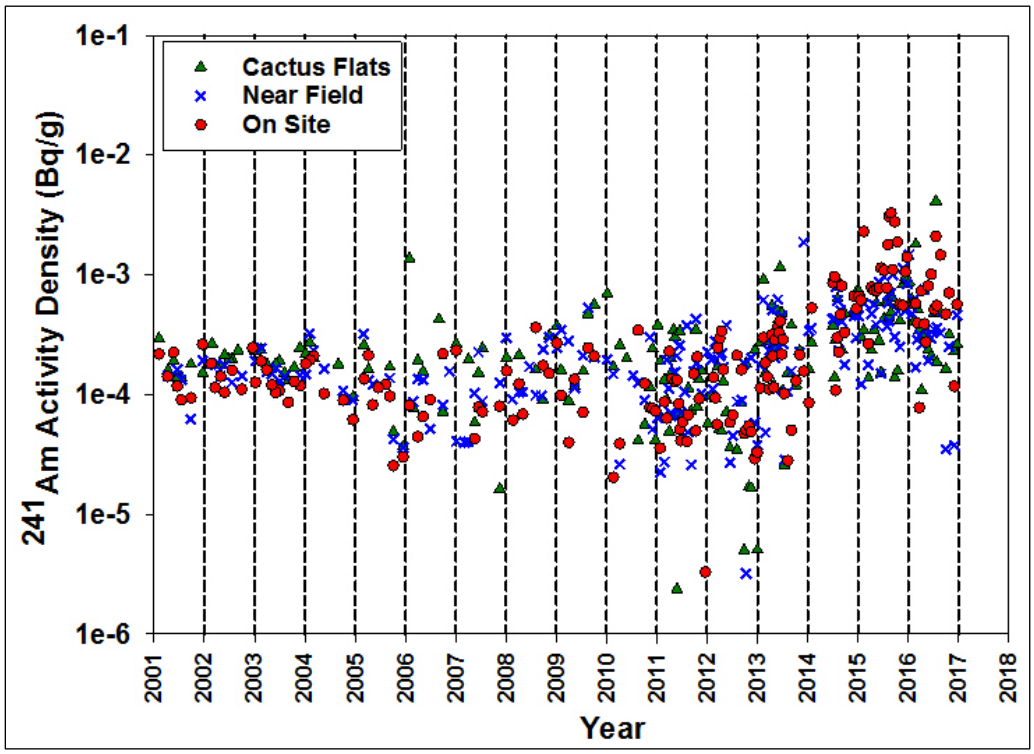


Figure 3-7: The Pre- and Post-radiological event ^{241}Am densities in ambient air at three stations in the vicinity of the WIPP site

Ambient Air Uranium Concentrations

Uranium is comprised of naturally occurring radionuclides found in the environment. Uranium occurs naturally in all rocks and soil with typical background levels ranging from approximately 2 to 4 mg/kg (Ahrens 1965, Wedepohl 1968). Thus, the detection of uranium in the ambient air is normal. Natural sources of uranium in ambient air include resuspension of soil and volcanic eruptions (ATSDR 1999; Kuroda et al. 1984); as well as anthropogenic sources of airborne uranium from coal and fuel combustion. The concentrations of uranium isotopes measured in the ambient air in the WIPP vicinity are listed in Table 3-19 (Onsite Station), Table 3-20 (Near Field Station) and Table 3-21 (Cactus Flats Station). The isotopes of uranium were detected at all sample locations. The highest concentrations detected were 2.26E-6 Bq/m^3 for ^{234}U and 2.46E-6 Bq/m^3 for ^{238}U measured at the Cactus Flats sampling station. The concentrations detected between the Onsite location and distant locations were not statistically different. The activity density of uranium isotopes measured in the ambient air filters during 2016 are listed in Table 3-22 (Onsite Station), Table 3-23 (Near Field Station) and Table 3-24 (Cactus Flats Station).

Uranium ratios are used to determine the type of uranium present in the environment. Natural uranium has a ^{235}U/^{238}U ratio of 0.00725, and ^{234}U/^{238}U ratio of 1.0. The average annual ^{234}U/^{238}U ratios of 1.07±0.09 at the Onsite Station, 1.06±0.06 at the Near Field station, and 1.06±0.09 at the Cactus Flats station are consistent with naturally occurring uranium. The uranium concentrations in the ambient air samples collected around WIPP site since 2011 are shown in Figures 3-8 and 3-9.

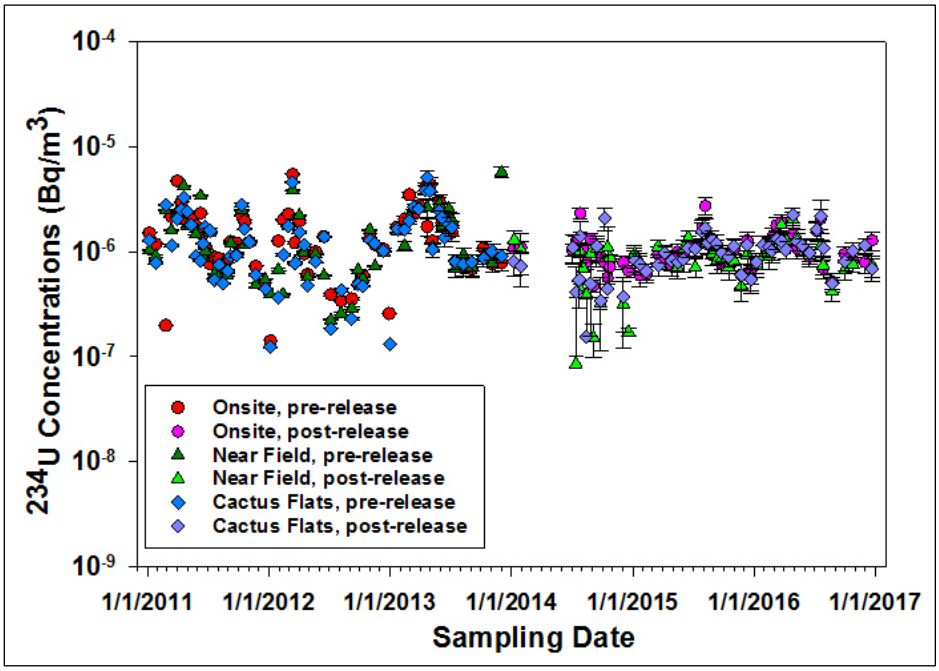


Figure 3-8: The Pre- and Post-radiological event ^{234}U concentrations in ambient air at three stations in the vicinity of the WIPP site

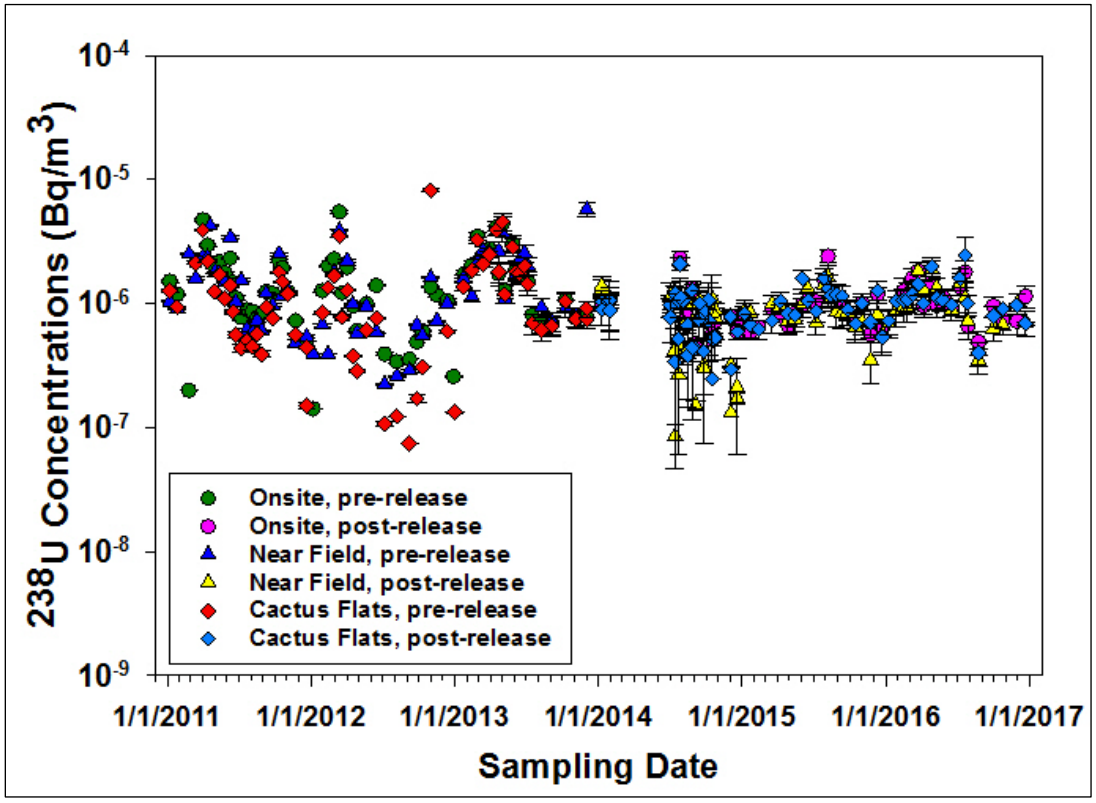


Figure 3-9: The Pre- and Post-radiological event ^{238}U concentrations in ambient air at three stations in the vicinity of the WIPP site

Ambient Air gamma radionuclide Concentrations

There were no measurable concentrations of ^{137}Cs or ^{60}Co in any of the ambient air filter samples collected following the radiation release event. However, ^{40}K was detected in a few ambient air filter samples. The ^{40}K is ubiquitous in the earth's crust and thus would be expected to show up in environmental air samples. There was no significant difference in the concentrations of ^{40}K among locations. The concentrations of ^{137}Cs and ^{40}K measured in ambient aerosol samples before and after the radiological event at WIPP are shown in Figures 3-10 through 3-18.

Additionally, there was no increase in gamma radionuclide concentrations that can be attributed to the February 14, 2014 underground radiation recent release event. The individual concentrations of these radionuclides measured in three aerosol stations are listed in Table 3-25 (Onsite Station), Table 3-26 (Near Field Station) and Table 3-27 (Cactus Flats Station). The individual activity densities of these radionuclides in these three monitoring stations are summarized in Table 3-28 (Onsite Station), Table 3-29 (Near Field Station) and Table 3-30 (Cactus Flats Station).

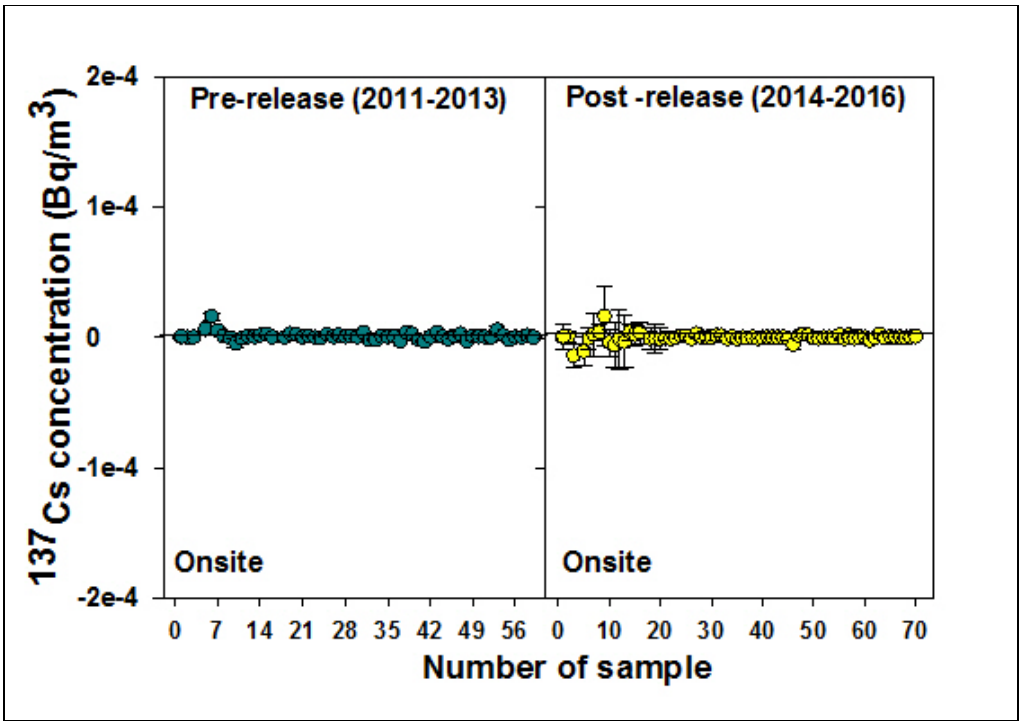


Figure 3-10: The Pre- and Post-release event ^{137}Cs concentrations in ambient air at Onsite station

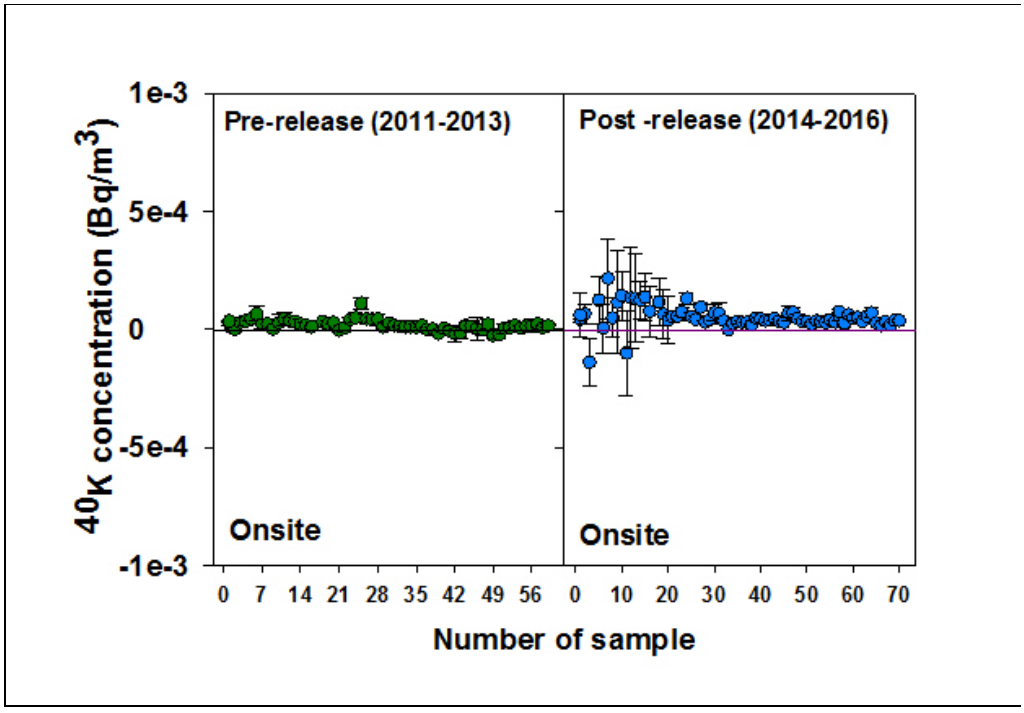


Figure 3-11: The Pre- and Post-radiological event ^{40}K concentrations in ambient air at Onsite station

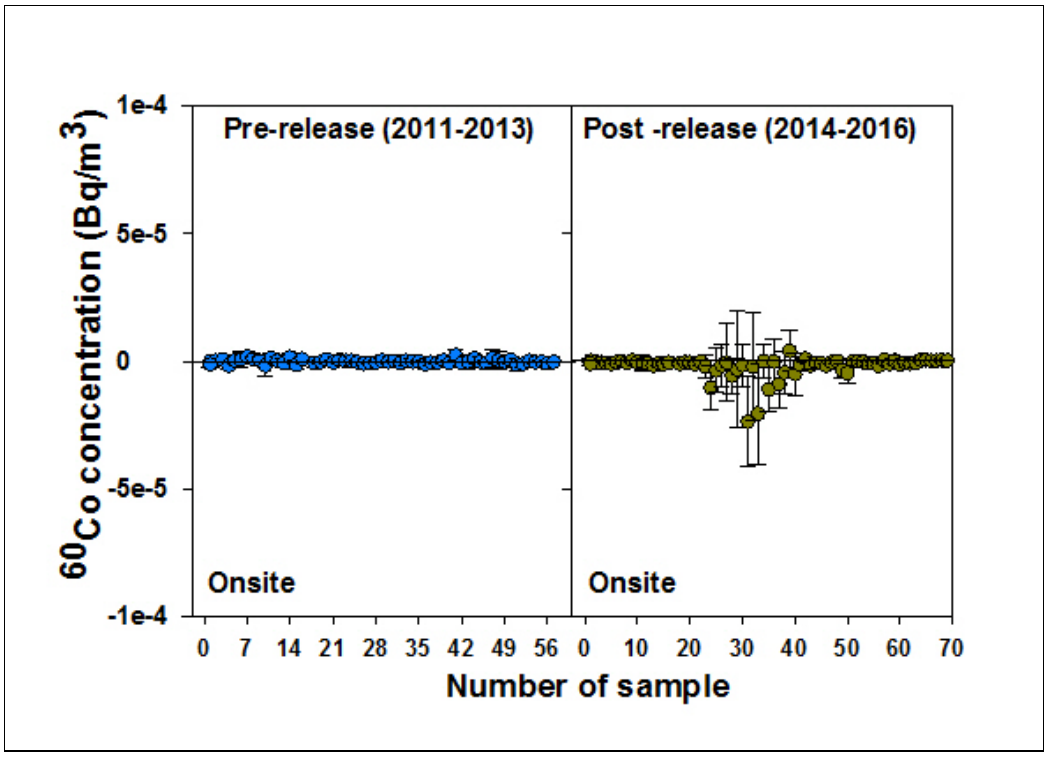


Figure 3-12: The Pre- and Post-radiological event ^{60}Co concentrations in ambient air at Onsite station

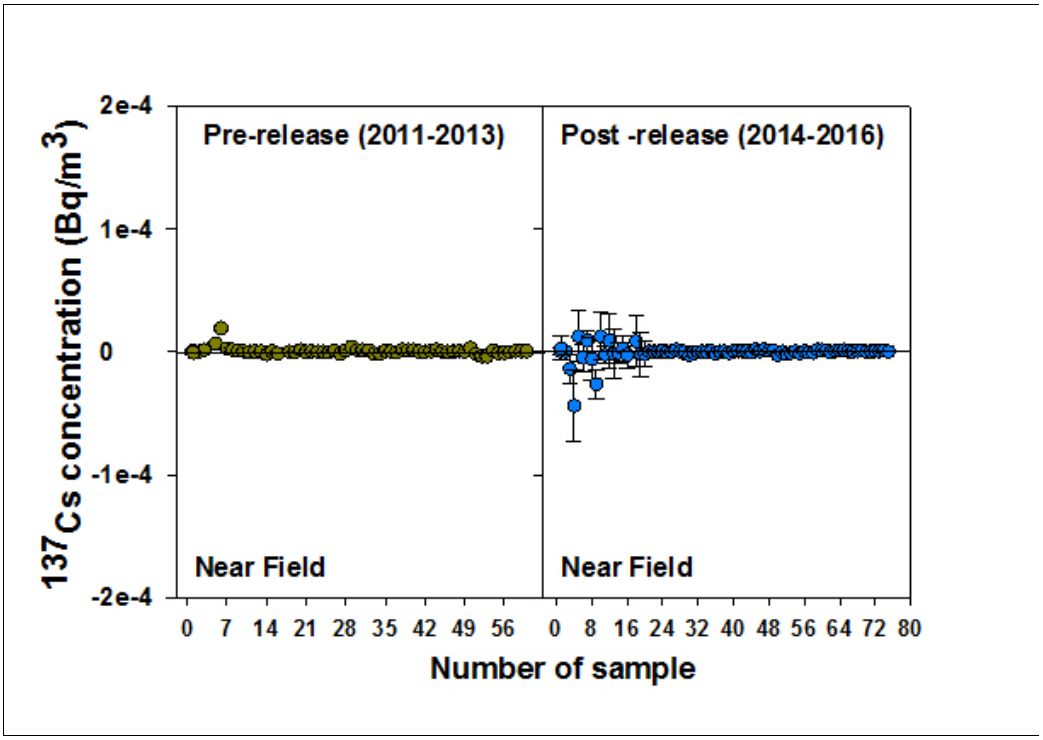


Figure 3-13: The Pre- and Post-radiological event ^{137}Cs concentrations in ambient air at Near Field station

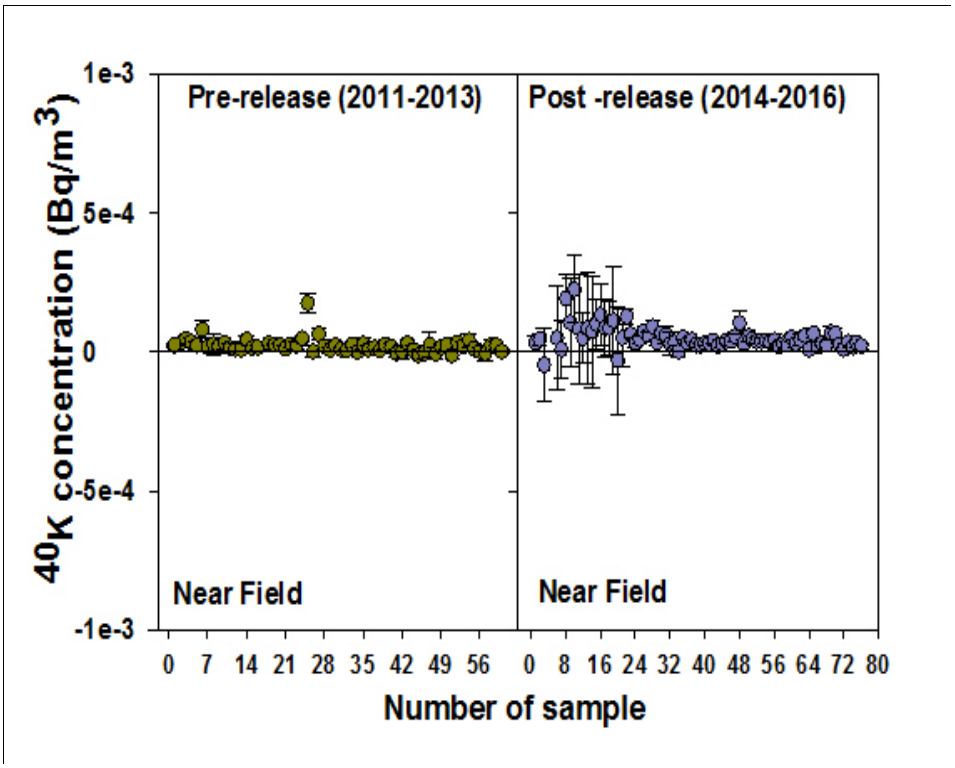


Figure 3-14: The Pre- and Post-radiological event ^{40}K concentrations in ambient air at Near Field station

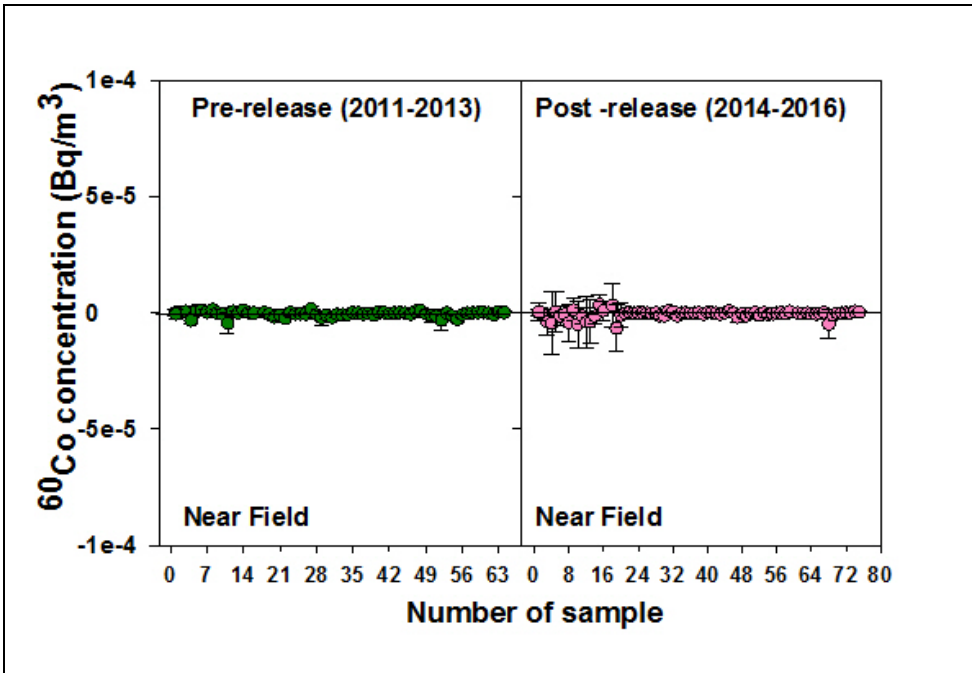


Figure 3-15: The Pre- and Post-radiological event ^{60}Co concentrations in ambient air at Near Field station

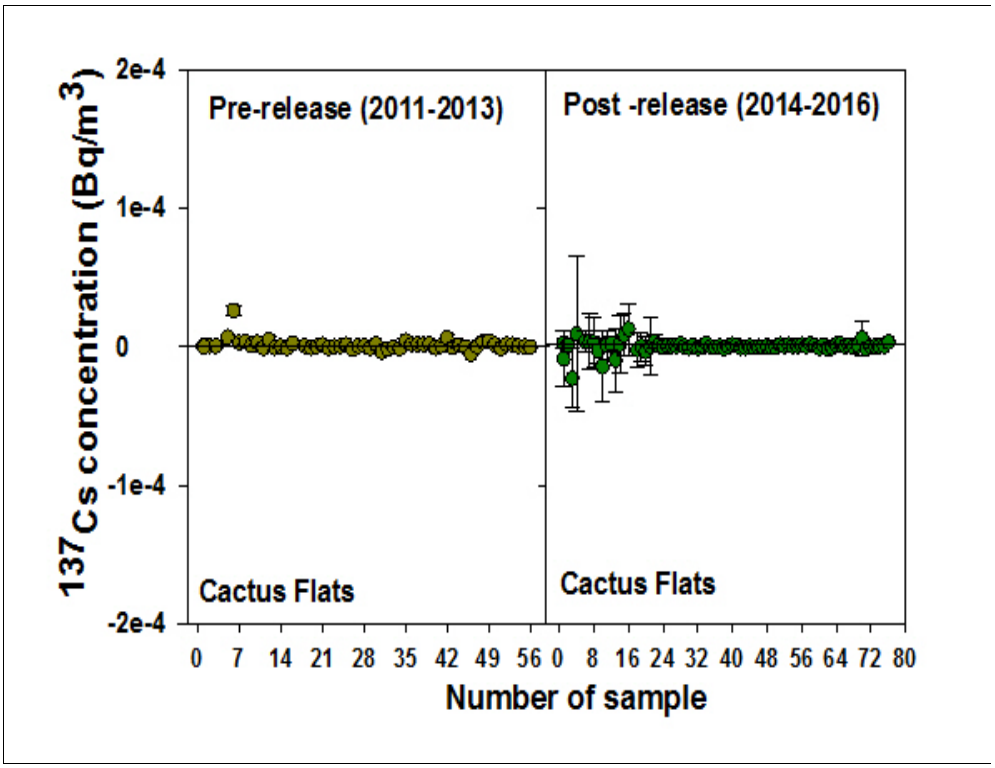


Figure 3-16: The Pre- and Post-radiological event ^{137}Cs concentrations in ambient air at Cactus Flats station

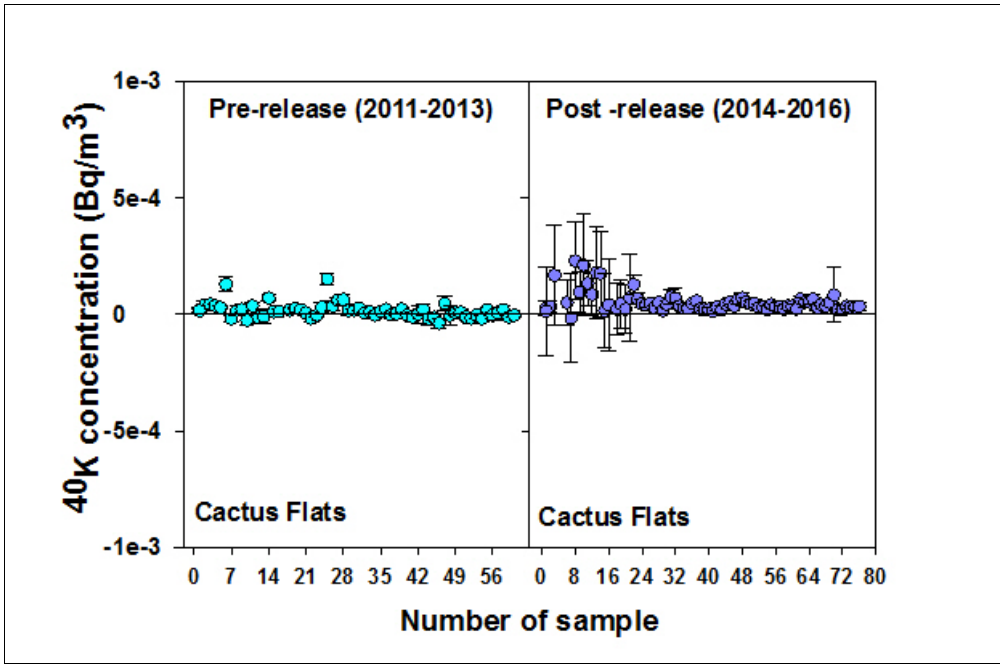


Figure 3-17: The Pre- and Post-radiological event ^{40}K concentrations in ambient air at Cactus Flats station

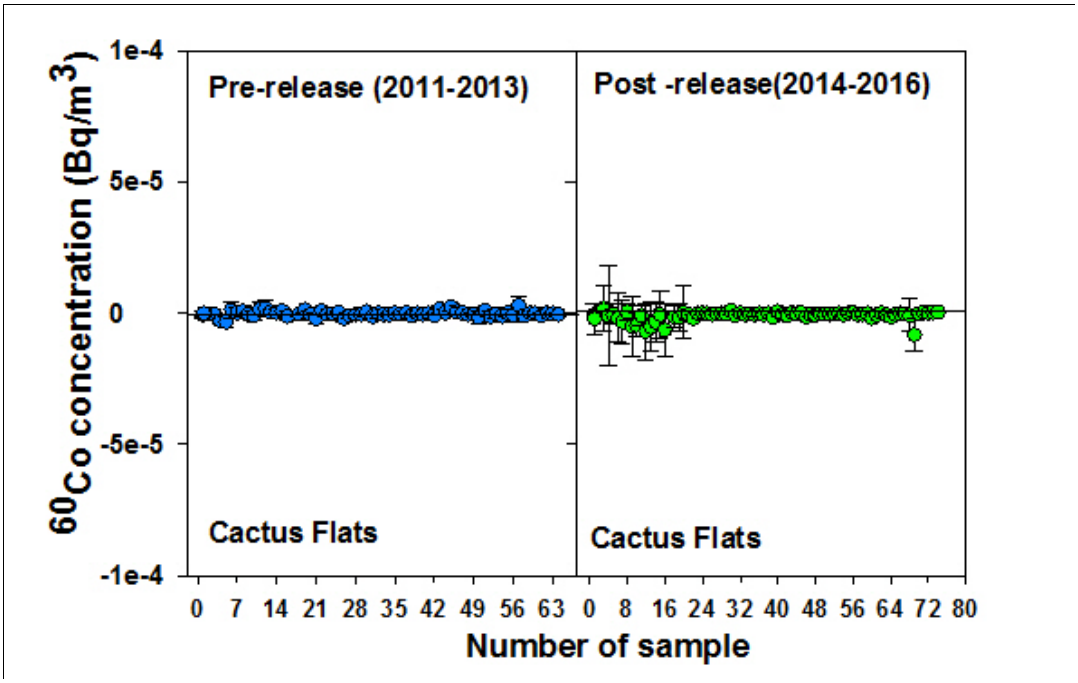


Figure 3-18: The Pre- and Post-radiological event ^{60}Co concentrations in ambient air at Cactus Flats station

Radionuclides concentrations at Carlsbad and Loving Air Monitoring Stations

The CEMRC began sampling at these two stations in May of 2015. The concentrations of $^{239+240}$Pu, ^{238}Pu and ^{241}Am measured are listed in Tables 3-31 (Loving) and 3-32 (Carlsbad) and are shown in Figures 3-19 through 3-21 (Loving) and Figures 3-22 through 3-24 (Carlsbad). The levels of $^{239+240}$Pu, ^{238}Pu and ^{241}Am in these monitoring stations are consistent with the normal background levels usually measured in the WIPP vicinity. The corresponding activity densities (activity per gram of dust) are summarized in Tables 3-33 and 3-34. The isotopes of uranium were detected at both sample locations. The concentrations of uranium isotopes measured are listed in Tables 3-35 (Loving) and 3-36 (Carlsbad) and are shown in Figures 3-25 and 3-26(Loving) and Figures 3-27 and 3-28 (Carlsbad). The levels detected were similar to those measured at other sample locations around the WIPP. The activity density of uranium isotopes measured in the ambient air filters during 2016 is listed in Tables 3-37 (Loving) and 3-38 (Carlsbad).

Gamma radionuclides (^{137}Cs or ^{60}Co) were not detected in any of the ambient air filter samples collected in 2016. However, ^{40}K was detected in a few ambient air filter samples. The activity concentrations of these gamma radionuclides measured are listed in Tables 3-39 (Loving) and 3-40 (Carlsbad) and shown in Figures 3-29 through 3-31 (Loving) and Figures 3-32 through 3-34 (Carlsbad). The corresponding activity density values are summarized in Tables 3- 41 (Loving) and 3-42 (Carlsbad).

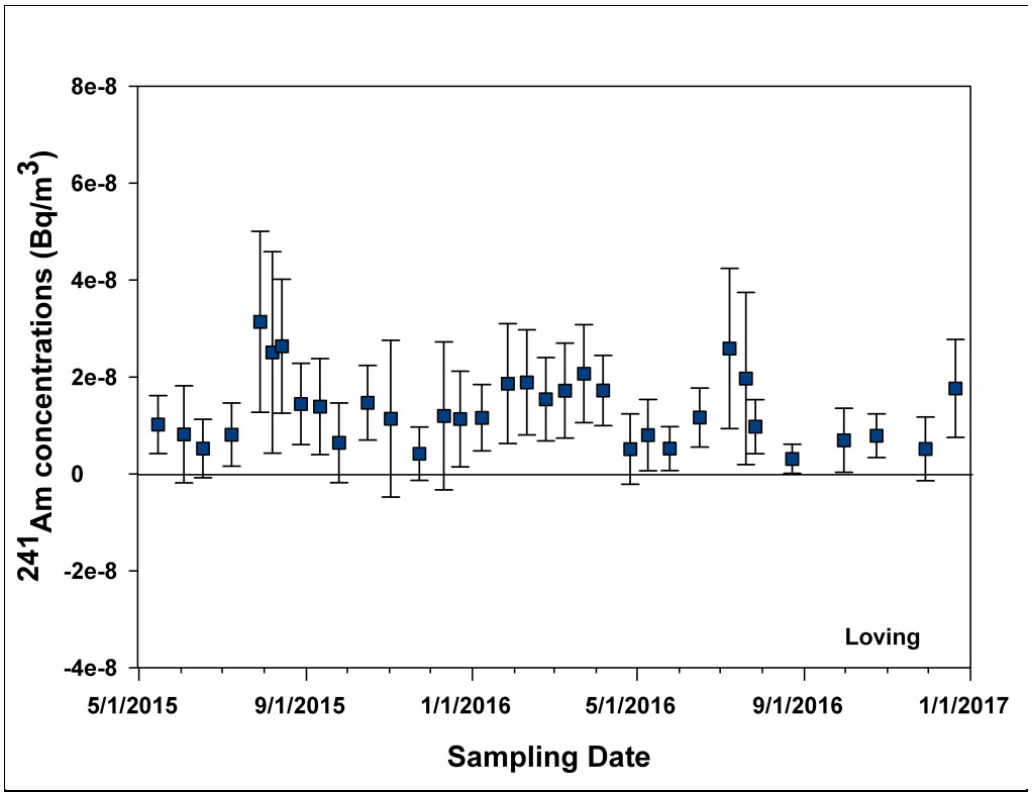


Figure 3-19: The ^{241}Am concentrations in ambient air at Loving station in 2015-2016

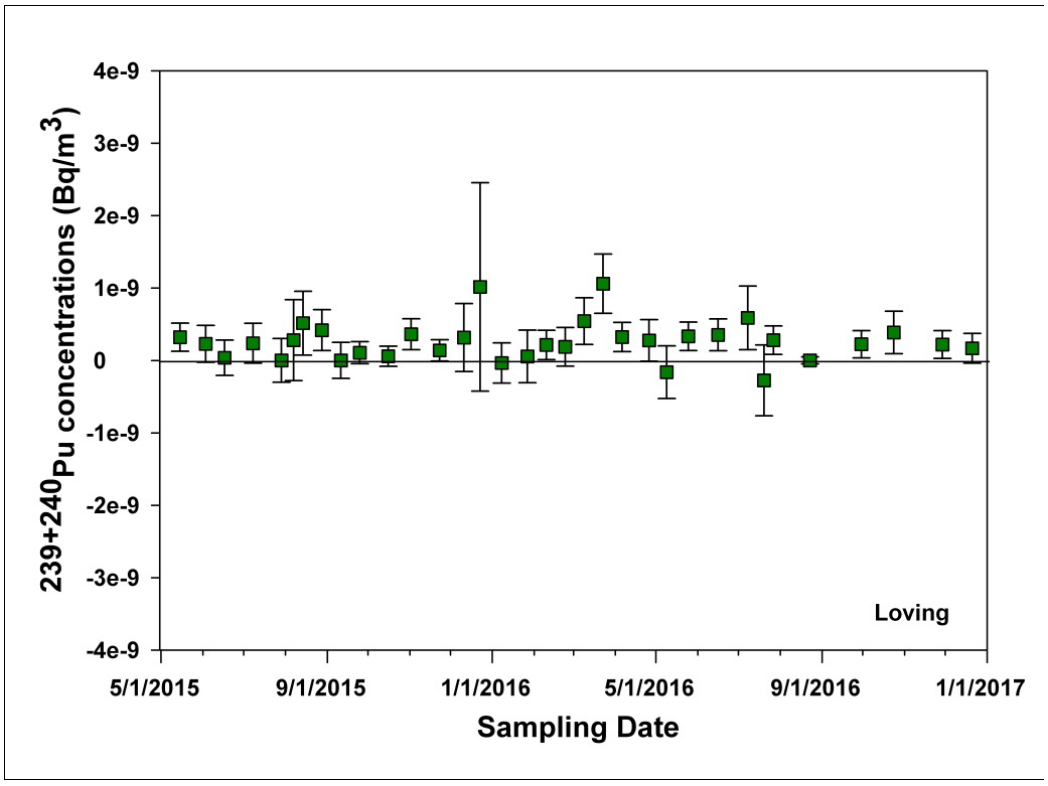


Figure 3-20: The $^{239+240}$Pu concentrations in ambient air at Loving station in 2015-2016

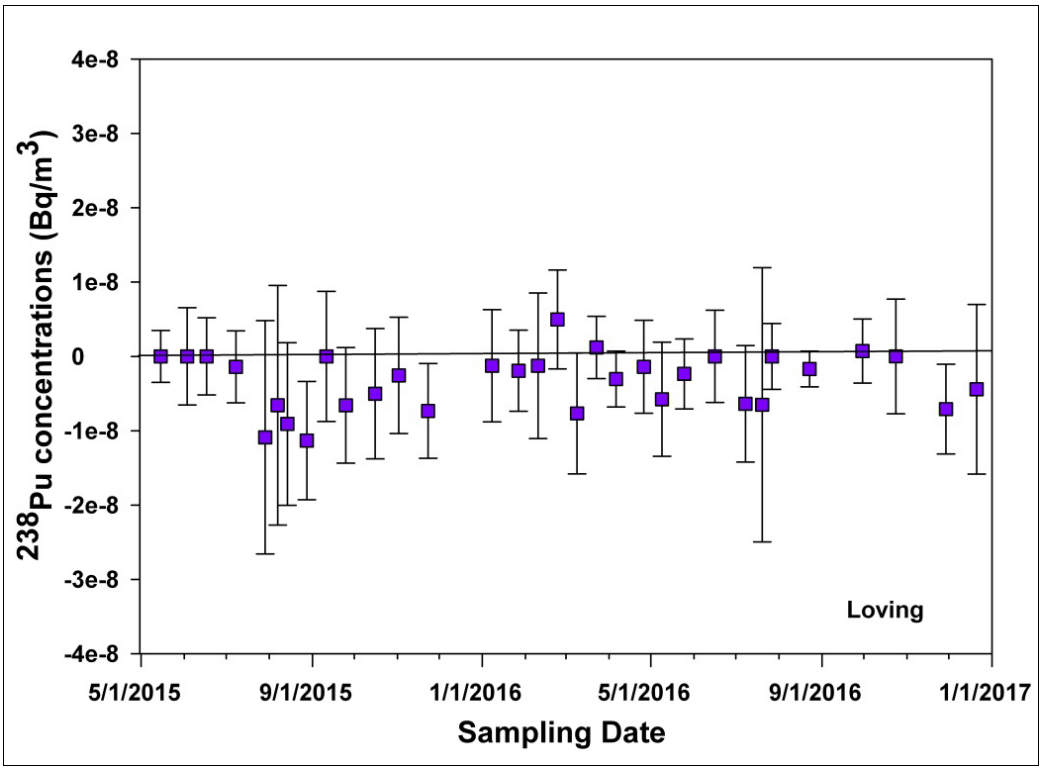


Figure 3-21: The ^{238}Pu concentrations in ambient air at Loving station in 2015-2016

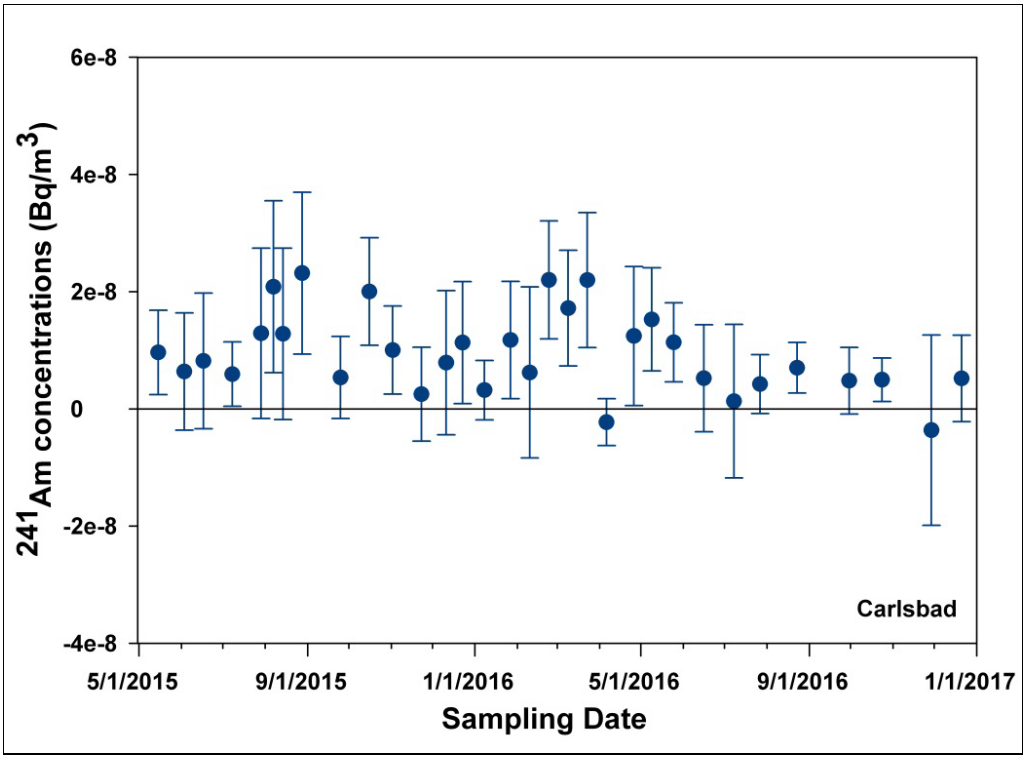


Figure 3-22: The ^{241}Am concentrations in ambient air at Carlsbad station in 2015-2016

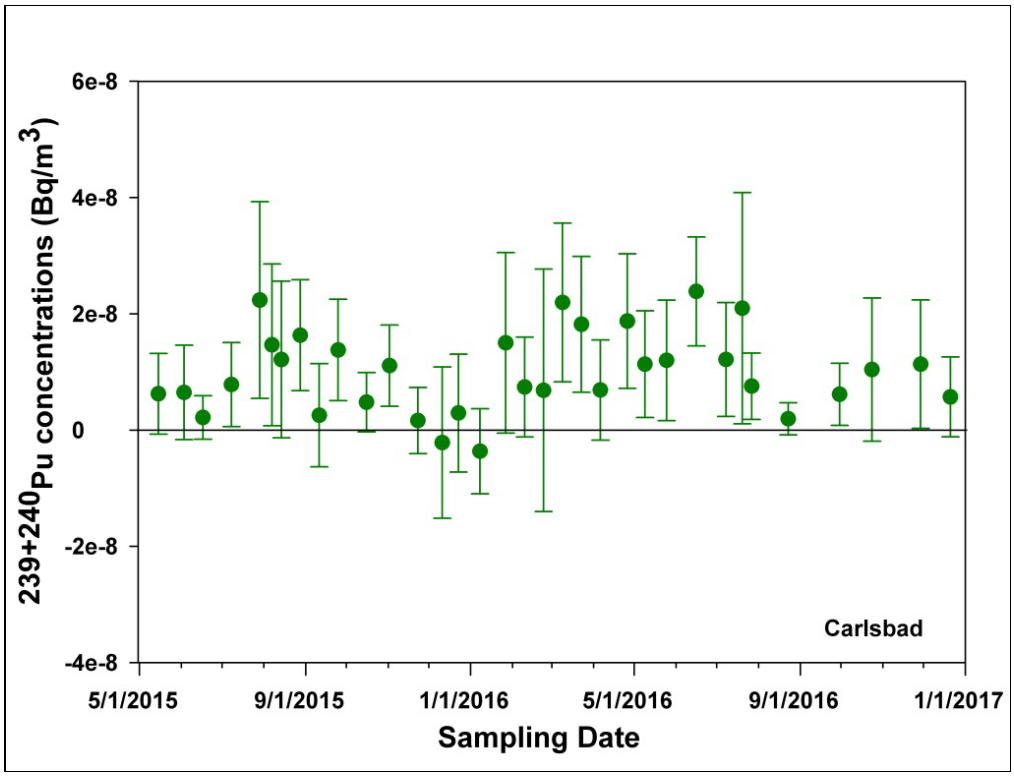


Figure 3-23: The $^{239+240}$Pu concentrations in ambient air at Carlsbad station in 2015-2016

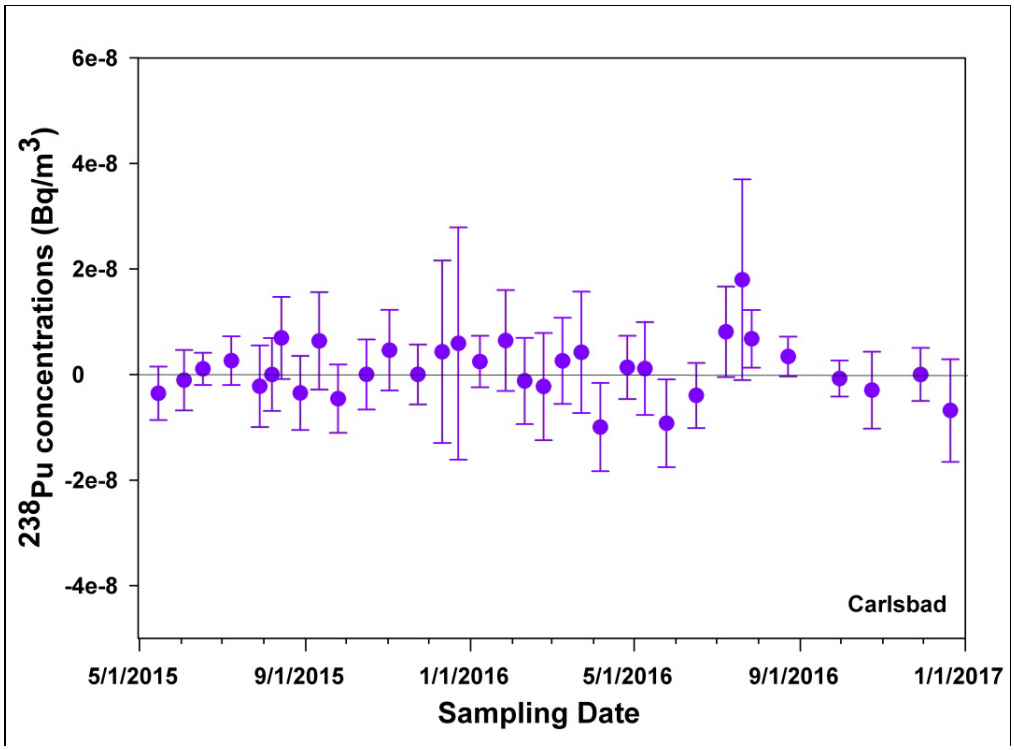


Figure 3-24: The ^{238}Pu concentrations in ambient air at Carlsbad station in 2015-2016

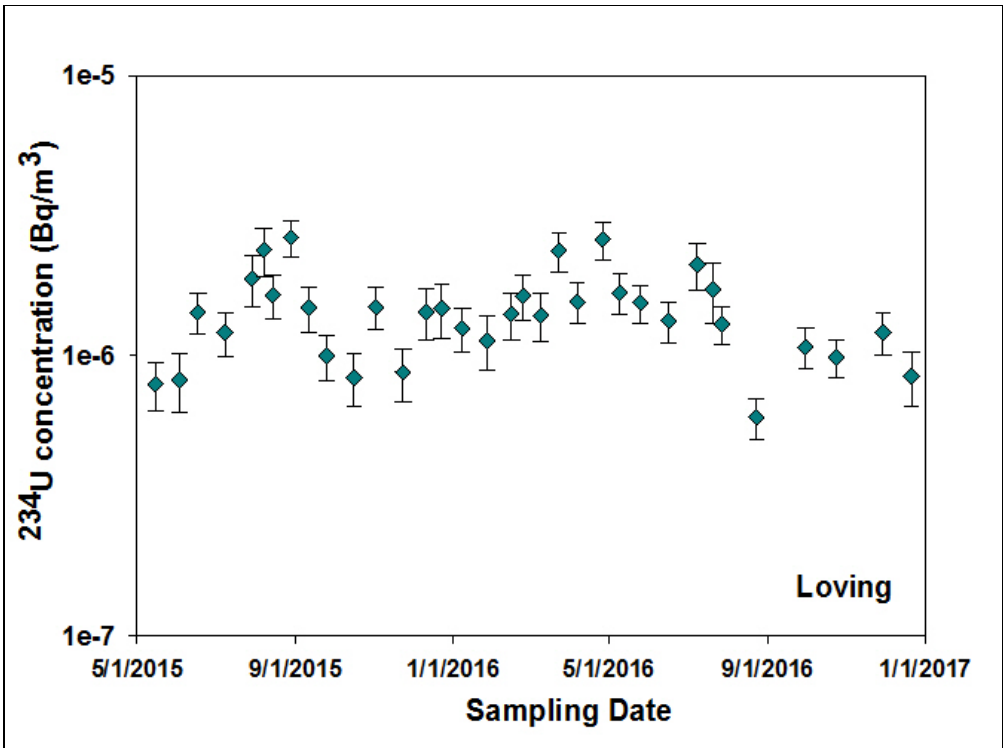


Figure 3-25: The ^{234}U concentrations in ambient air at Loving station in 2015-2016

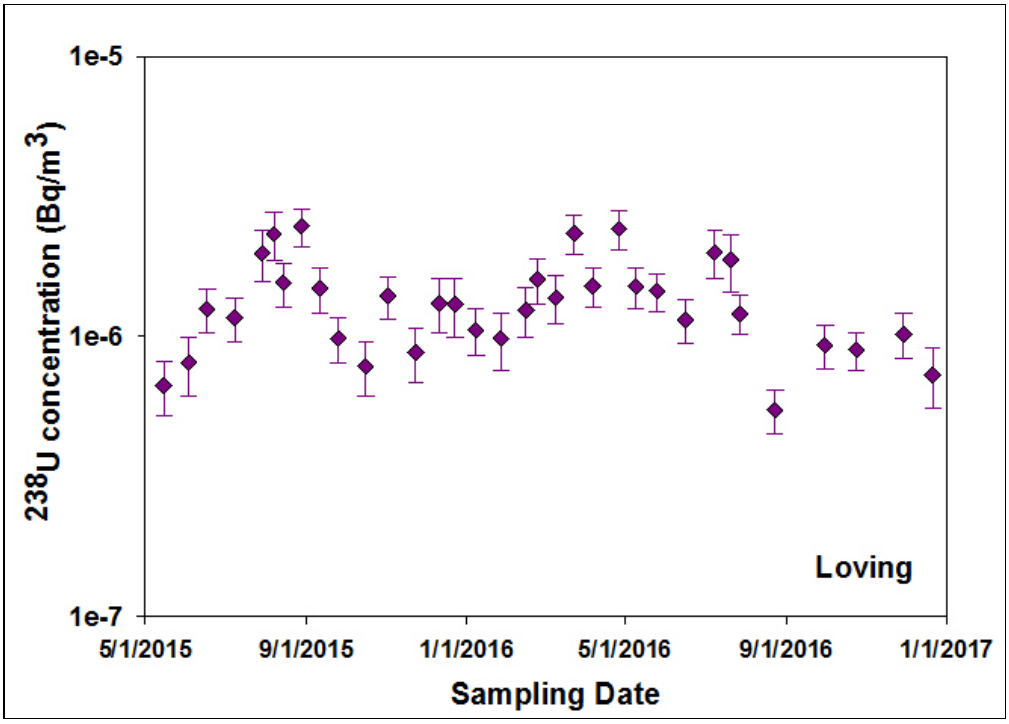


Figure 3-26: The ^{238}U concentrations in ambient air at Loving station in 2015-2016

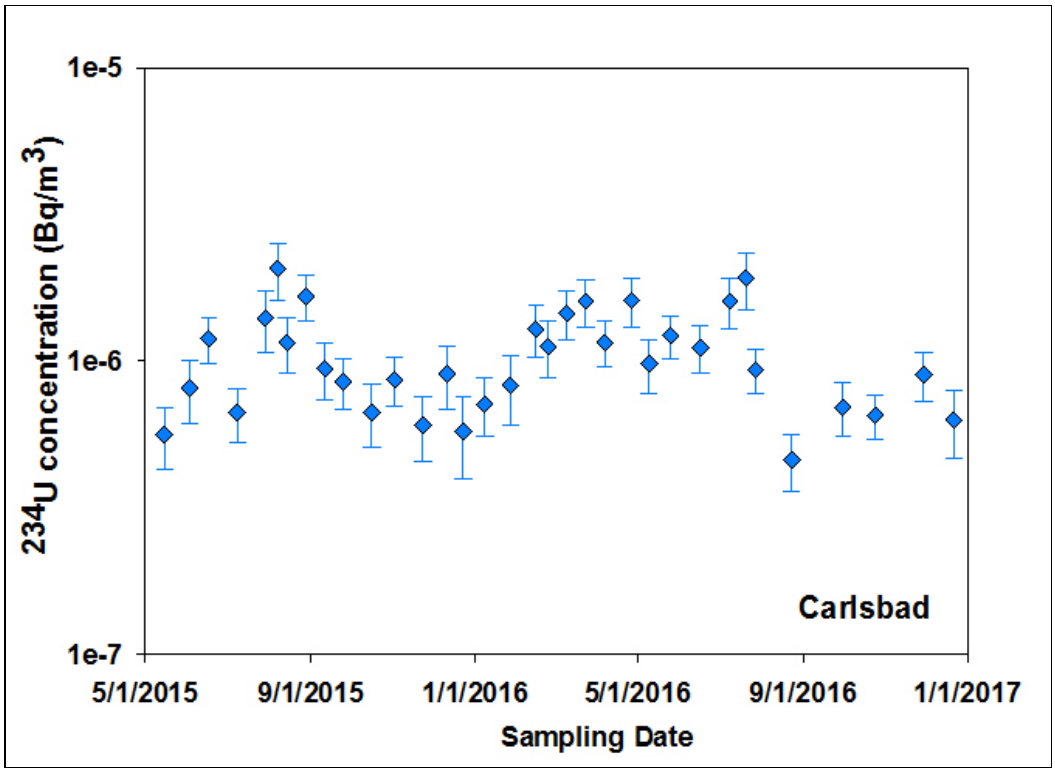


Figure 3-27: The ^{234}U concentrations in ambient air at Carlsbad station in 2015-2016

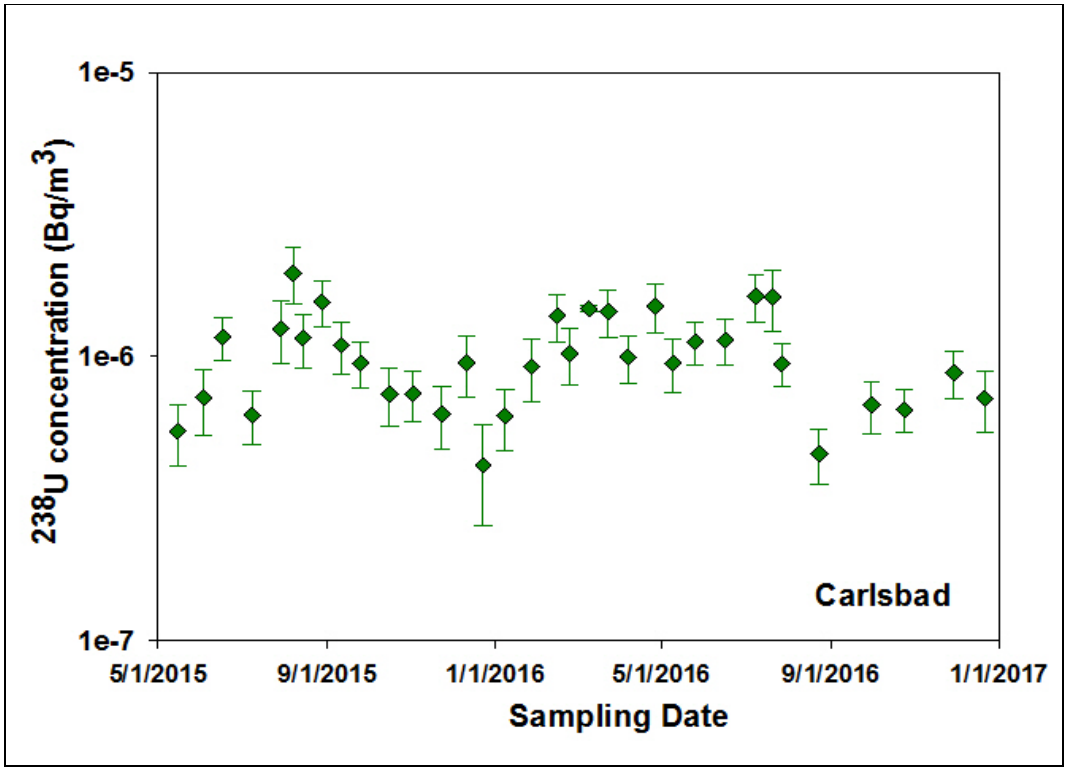


Figure 3-28: The ^{238}U concentrations in ambient air at Carlsbad station in 2015-2016

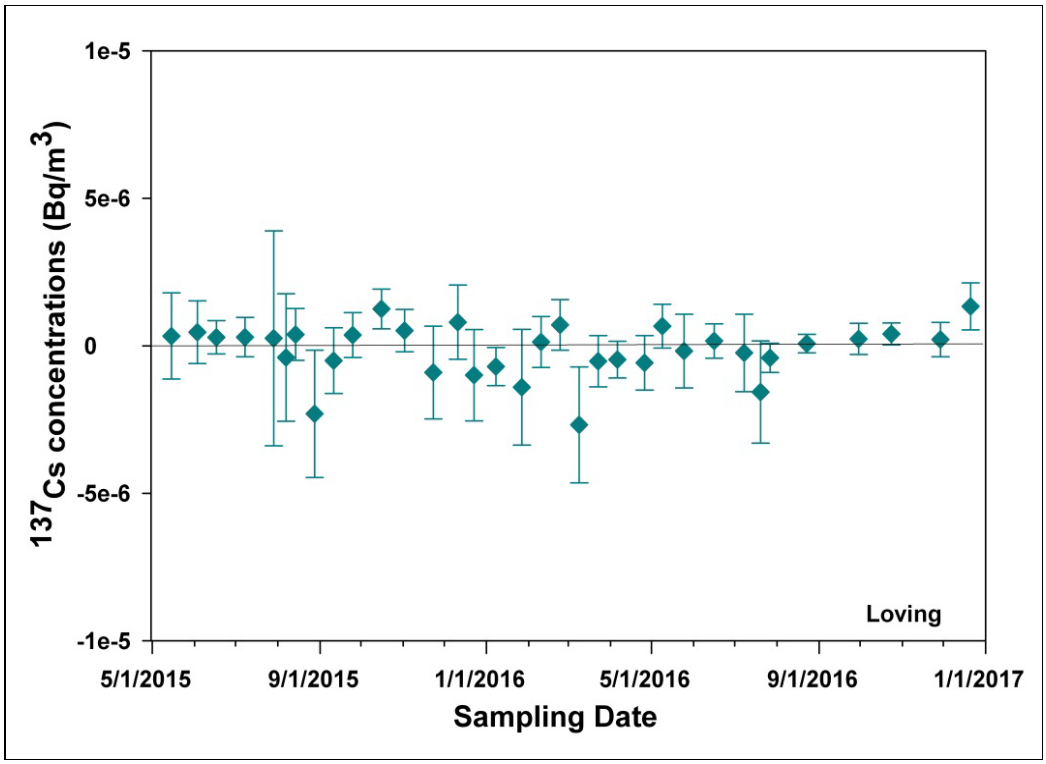


Figure 3-29: The ^{137}Cs concentrations in ambient air at Loving station in 2015-2016

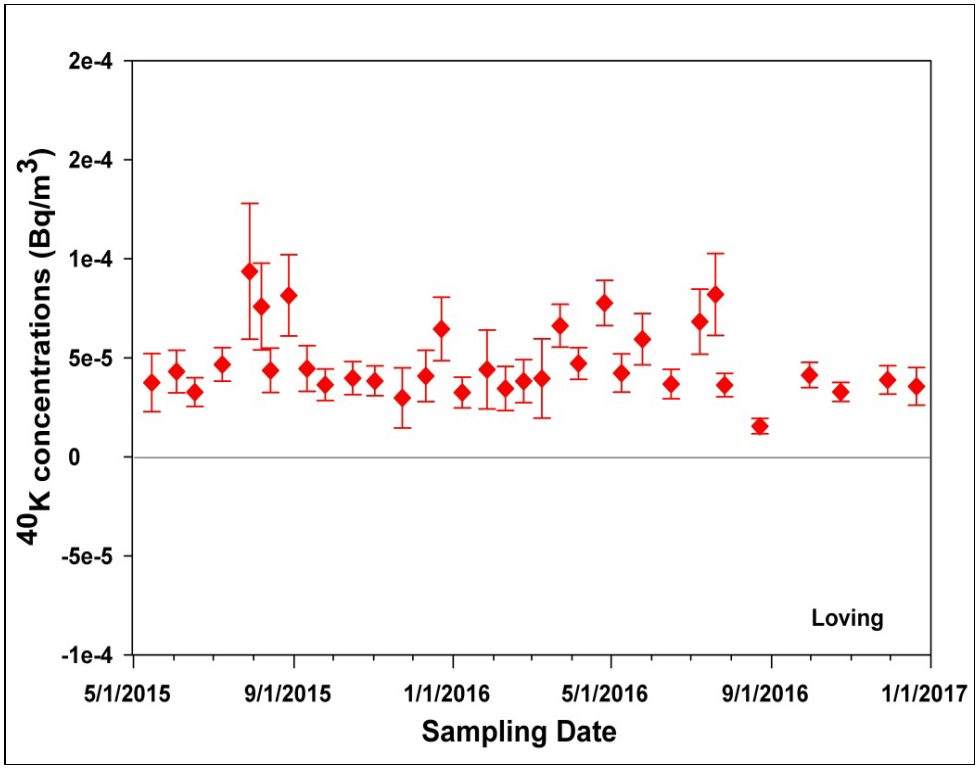


Figure 3-30: The ^{40}K concentrations in ambient air at Loving station in 2015-2016

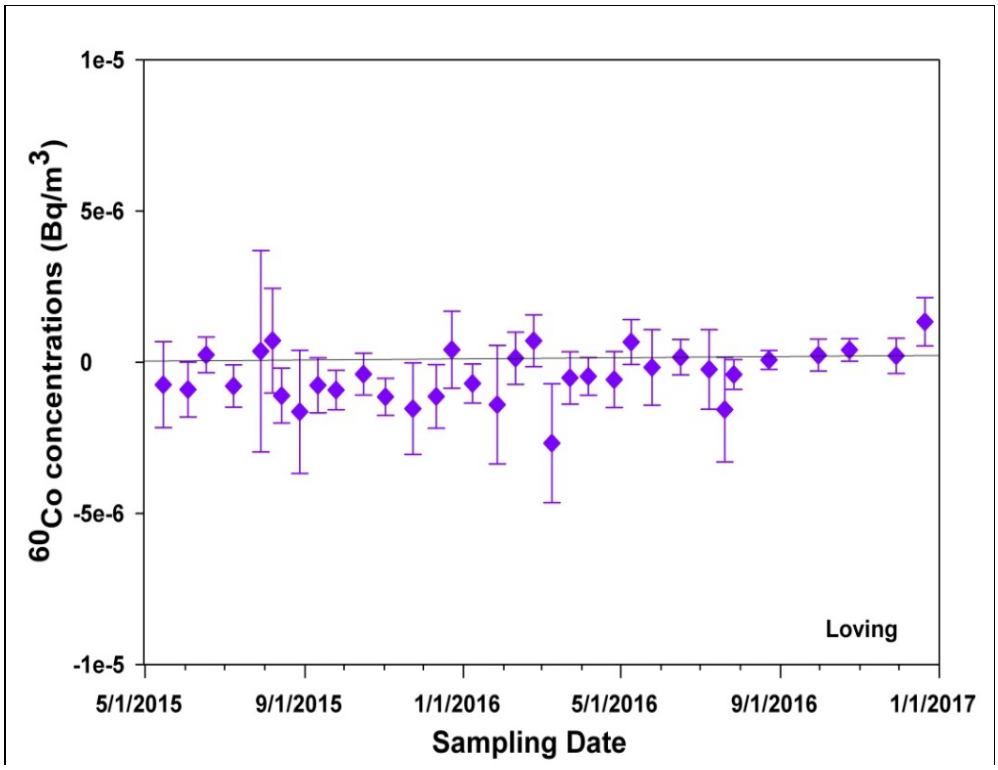


Figure 3-31: The ^{60}Co concentrations in ambient air at Loving station in 2015-2016

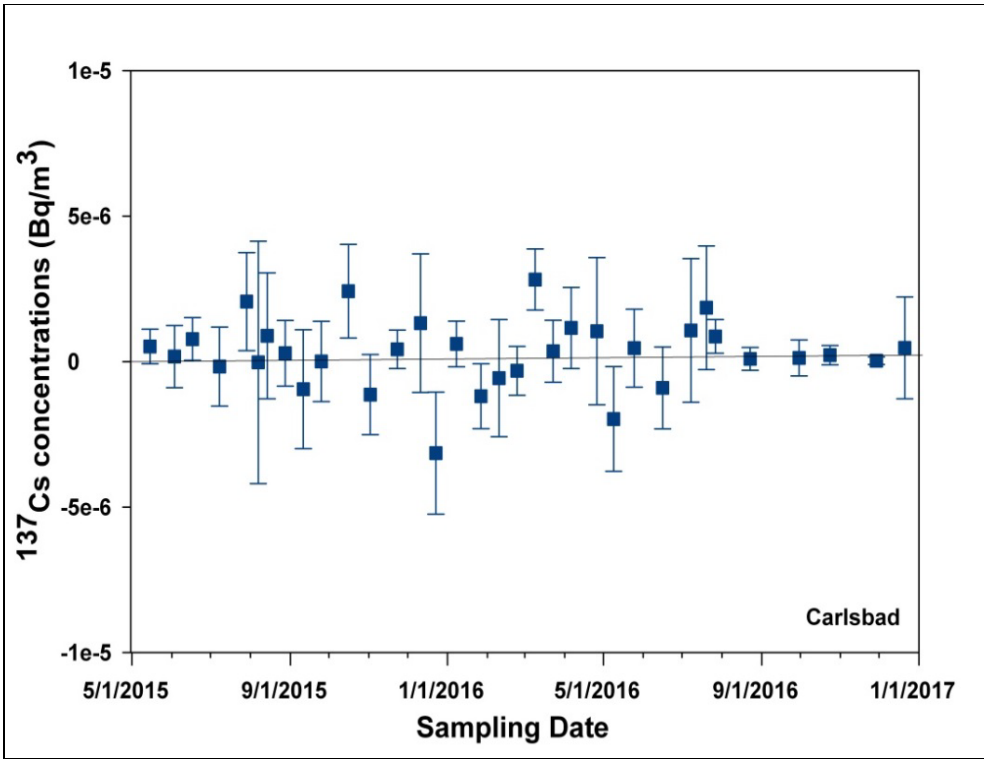


Figure 3-32: The ^{137}Cs concentrations in ambient air at Carlsbad station in 2015-2016

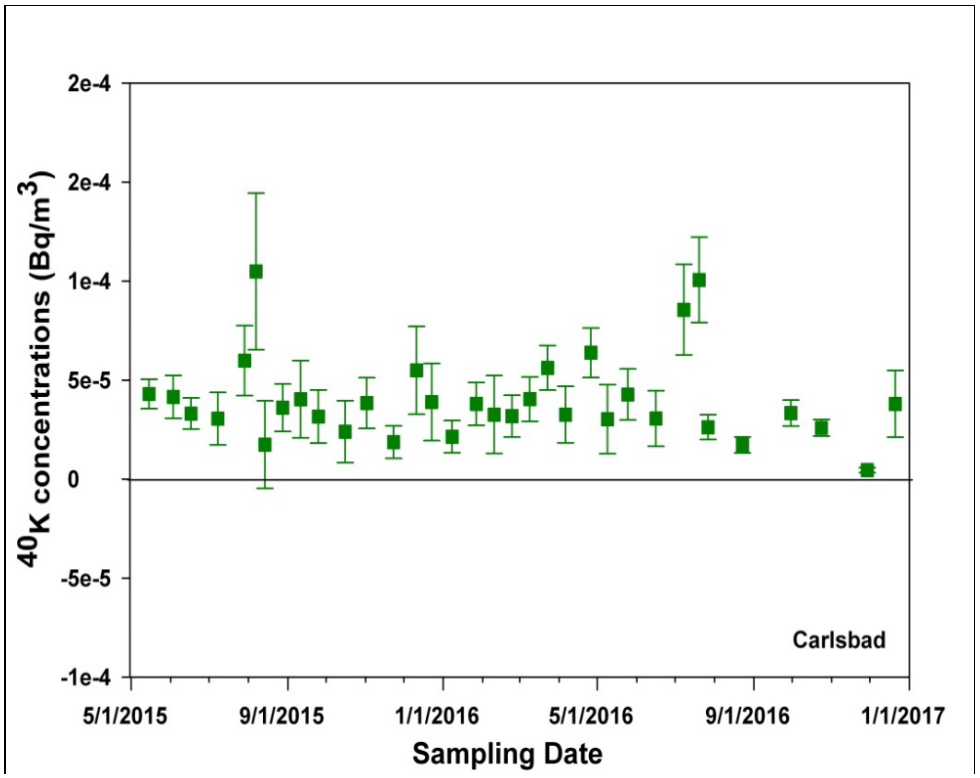


Figure 3-33: The ^{40}K concentrations in ambient air at Carlsbad station in 2015-2016

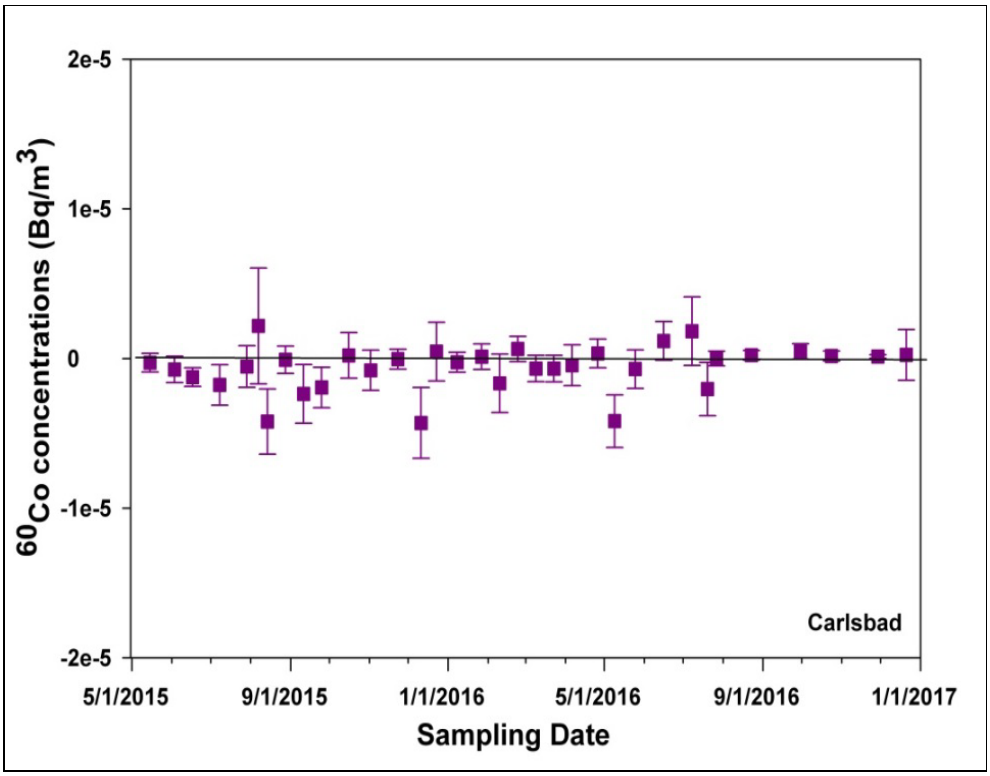


Figure 3-34: The ^{60}Co concentrations in ambient air at Carlsbad station in 2015-2016

Table 3-1: Activity concentrations of ^{241}Am in the filter samples collected from Onsite Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc.(2σ) Bq/m^3	MDC Bq/m^3	Status
^{241}Am	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	2.78E-08	1.60E-08	2.44E-08	Detected
	Feb. 24 – Mar. 9	1.89E-08	1.17E-08	1.87E-08	Detected
	Mar. 9 – Mar. 23	2.01E-08	1.24E-08	2.06E-08	Not detected
	Mar. 23 – Apr. 6	3.97E-09	1.34E-08	1.11E-08	Not detected
	Apr. 6 – Apr. 26	2.47E-08	1.17E-08	1.56E-08	Detected
	Apr. 26 – May 9	2.38E-08	1.17E-08	1.37E-08	Detected
	May 9 – May 25	1.13E-08	8.92E-09	1.72E-08	Not detected
	May 25 – Jun. 16	2.94E-08	1.00E-08	1.04E-08	Detected
	Jun. 16 – Jul. 8	3.11E-08	1.14E-08	1.04E-08	Detected
	Jul. 8 – Jul. 20	2.31E-08	1.37E-08	2.29E-08	Detected
	Jul. 20 – Jul. 27	9.56E-08	3.56E-08	4.57E-08	Detected
	Jul. 27 – Aug. 23	1.67E-08	7.54E-09	1.04E-08	Detected
	Aug. 23 – Sep. 30	3.03E-08	7.86E-09	5.55E-09	Detected
	Sep. 30 – Oct. 24	1.79E-08	8.30E-09	1.30E-08	Detected
	Oct. 24 – Nov. 29	2.08E-08	7.77E-09	5.83E-09	Detected
	Nov. 29 – Dec. 21	4.15E-09	5.45E-09	1.19E-08	Not detected
	Dec. 21 – Jan. 6	1.09E-08	9.45E-09	1.89E-08	Not detected

*sampler was offline due to power outage

Table 3-2: Activity concentrations of $^{239+240}$Pu in the filter samples collected from Onsite Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
$^{239+240}$Pu	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	2.32E-09	6.58E-09	1.71E-08	Not detected
	Feb. 24 – Mar. 9	1.83E-08	1.70E-08	3.23E-08	Not detected
	Mar. 9 – Mar. 23	3.06E-08	1.77E-08	2.81E-08	Detected
	Mar. 23 – Apr. 6	4.13E-09	1.13E-08	1.13E-08	Not detected
	Apr. 6 – Apr. 26	1.19E-08	9.59E-09	1.26E-08	Not detected
	Apr. 26 – May 9	1.73E-08	1.12E-08	1.60E-08	Detected
	May 9 – May 25	1.76E-08	1.18E-08	2.07E-08	Not detected
	May 25 – Jun. 16	2.30E-09	8.82E-09	2.16E-08	Not detected
	Jun. 16 – Jul. 8	1.42E-08	6.94E-09	8.14E-09	Detected

*sampler was offline due to power outage

Table 3-2: Activity concentrations of $^{239+240}$Pu in the filter samples collected from Onsite Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
$^{239+240}$Pu	Jul. 8 – Jul. 20	1.69E-08	1.26E-08	2.26E-08	Not detected
	Jul. 20 – Jul. 27	3.04E-08	2.55E-08	4.79E-08	Not detected
	Jul. 27 - Aug. 23	2.66E-09	4.99E-09	1.16E-08	Not detected
	Aug. 23 – Sep. 30	9.87E-09	4.82E-09	5.65E-09	Detected
	Sep. 30 – Oct. 24	1.06E-08	7.04E-09	1.24E-08	Not detected
	Oct. 24 – Nov. 29	5.41E-09	8.43E-09	1.89E-08	Not detected
	Nov. 29 – Dec. 21	8.01E-09	1.00E-08	2.11E-08	Not detected
	Dec. 21 – Jan. 6	-4.97E-09	9.98E-09	3.12E-08	Not detected

Table 3-3: Activity concentrations of ^{238}Pu in the filter samples collected from Onsite Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{238}Pu	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	2.32E-09	6.58E-09	1.71E-08	Not detected
	Feb. 24 – Mar. 9	0.00E+00	5.77E-09	1.89E-08	Not detected
	Mar. 9 – Mar. 23	0.00E+00	9.11E-09	2.55E-08	Not detected
	Mar. 23 – Apr. 6	5.34E-16	6.33E-09	1.78E-08	Not detected
	Apr. 6 – Apr. 26	-3.98E-09	6.56E-09	1.95E-08	Not detected
	Apr. 26 – May 9	-4.01E-09	7.08E-09	2.32E-08	Not detected
	May 9 – May 25	-1.96E-09	3.82E-09	1.32E-08	Not detected
	May 25 – Jun. 16	-3.07E-09	4.87E-09	1.55E-08	Not detected
	Jun. 16 – Jul. 8	-6.08E-09	7.05E-09	2.08E-08	Not detected
	Jul. 8 – Jul. 20	2.59E-09	7.35E-09	1.83E-08	Not detected
	Jul. 20 – Jul. 27	2.75E-09	1.46E-08	3.89E-08	Not detected
	Jul. 27 - Aug. 23	-6.67E-10	2.98E-09	9.39E-09	Not detected
	Aug. 23 – Sep. 30	-9.41E-10	5.48E-09	1.44E-08	Not detected
	Sep. 30 – Oct. 24	-3.29E-09	3.96E-09	1.32E-08	Not detected
	Oct. 24 – Nov. 29	2.17E-09	5.31E-09	1.30E-08	Not detected
	Nov. 29 – Dec. 21	-1.34E-09	8.85E-09	2.51E-08	Not detected
	Dec. 21 – Jan. 6	-1.49E-08	1.37E-08	4.38E-08	Not detected

*sampler was offline due to power outage

Table 3-4: Activity concentrations of ^{241}Am in the filter samples collected from Near Field station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{241}Am	Jan. 8 – Jan. 27	2.76E-08	1.02E-08	7.53E-09	Detected
	Jan. 27 – Feb. 10	1.26E-08	7.70E-09	7.83E-09	Detected
	Feb. 10 – Feb. 24	1.35E-08	9.62E-09	1.48E-08	Not detected
	Feb. 24 – Mar. 9	5.91E-09	9.77E-09	2.22E-08	Not detected
	Mar. 9 – Mar. 23	1.30E-08	9.83E-09	1.67E-08	Not detected
	Mar. 23 – Apr. 6	1.75E-08	1.22E-08	2.20E-08	Not detected
	Apr. 6 – Apr. 26	9.36E-09	5.77E-09	8.07E-09	Detected
	Apr. 26 – May 9	3.64E-08	2.95E-08	4.86E-08	Not detected
	May 9 – May 25	1.24E-08	8.41E-09	1.44E-08	Not detected
	May 25 – Jun. 16	6.98E-09	6.79E-09	1.35E-08	Not detected
	Jun. 16 – Jul. 8	9.18E-09	6.41E-09	8.54E-09	Detected
	Jul. 8 – Jul. 20	1.57E-08	1.27E-08	2.43E-08	Not detected
	Jul. 20 – Jul. 27	1.38E-08	1.63E-08	3.43E-08	Not detected
	Jul. 27 - Aug. 23	9.54E-09	5.49E-09	7.91E-09	Detected
	Aug. 23 – Sep. 30	6.43E-09	3.84E-09	5.66E-09	Detected
	Sep. 30 – Oct. 24	1.14E-09	6.27E-09	1.56E-08	Not detected
	Oct. 24 – Nov. 29	7.50E-09	4.21E-09	6.55E-09	Detected
	Nov. 29 – Dec. 21	1.23E-09	5.50E-09	1.38E-08	Not detected
	Dec. 21 – Jan. 6	7.87E-09	8.79E-09	1.87E-08	Not detected

Table 3-5: Activity concentrations of $^{239+240}$Pu in the filter samples collected from Near Field Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
$^{239+240}$Pu	Jan. 8 – Jan. 27	1.66E-08	9.48E-09	1.37E-08	Detected
	Jan. 27 – Feb. 10	1.21E-08	1.16E-08	1.88E-08	Not detected
	Feb. 10 – Feb. 24	3.53E-09	1.06E-08	2.12E-08	Not detected
	Feb. 24 – Mar. 9	5.17E-09	1.25E-08	3.01E-08	Not detected
	Mar. 9 – Mar. 23	-1.27E-09	1.49E-08	3.87E-08	Not detected
	Mar. 23 – Apr. 6	1.11E-08	1.25E-08	2.62E-08	Not detected
	Apr. 6 – Apr. 26	5.10E-09	9.04E-09	2.09E-08	Not detected
	Apr. 26 – May 9	1.82E-08	1.06E-08	1.21E-08	Detected
	May 9 – May 25	6.33E-09	1.02E-08	2.34E-08	Not detected
	May 25 – Jun. 16	7.69E-09	9.24E-09	2.01E-08	Not detected
	Jun. 16 – Jul. 8	3.39E-09	6.35E-09	1.47E-08	Not detected
	Jul. 8 – Jul. 20	2.03E-08	1.60E-08	3.09E-08	Not detected
	Jul. 20 – Jul. 27	3.15E-15	2.64E-08	7.04E-08	Not detected

Table 3-5: Activity concentrations of $^{239+240}$Pu in the filter samples collected from Near Field Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
$^{239+240}$Pu	Jul. 27 - Aug. 23	7.47E-09	6.65E-09	1.33E-08	Not detected
	Aug. 23 – Sep. 30	3.81E-09	3.90E-09	8.13E-09	Not detected
	Sep. 30 – Oct. 24	3.38E-09	7.30E-09	1.72E-08	Not detected
	Oct. 24 – Nov. 29	1.54E-08	8.83E-09	1.27E-08	Detected
	Nov. 29 – Dec. 21	1.50E-08	1.30E-08	2.35E-08	Not detected
	Dec. 21 – Jan. 6	2.28E-08	1.98E-08	3.57E-08	Not detected

Table 3-6: Activity concentrations of ^{238}Pu in the filter samples collected from Near Field Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{238}Pu	Jan. 8 – Jan. 27	-1.94E-09	3.90E-09	1.37E-08	Not detected
	Jan. 27 – Feb. 10	-4.05E-09	9.95E-09	3.21E-08	Not detected
	Feb. 10 – Feb. 24	8.83E-09	1.06E-08	2.12E-08	Not detected
	Feb. 24 – Mar. 9	1.72E-09	7.71E-09	2.07E-08	Not detected
	Mar. 9 – Mar. 23	-1.27E-09	9.74E-09	2.69E-08	Not detected
	Mar. 23 – Apr. 6	6.64E-16	6.84E-09	1.96E-08	Not detected
	Apr. 6 – Apr. 26	8.52E-10	5.64E-09	1.48E-08	Not detected
	Apr. 26 – May 9	-3.11E-16	5.21E-09	1.56E-08	Not detected
	May 9 – May 25	-1.04E-09	4.66E-09	1.47E-08	Not detected
	May 25 – Jun. 16	3.42E-09	5.42E-09	1.21E-08	Not detected
	Jun. 16 – Jul. 8	1.60E-09	4.55E-09	1.13E-08	Not detected
	Jul. 8 – Jul. 20	5.85E-09	1.18E-08	2.75E-08	Not detected
	Jul. 20 – Jul. 27	-1.09E-15	1.12E-08	3.22E-08	Not detected
	Jul. 27 - Aug. 23	-2.98E-16	3.06E-09	8.82E-09	Not detected
	Aug. 23 – Sep. 30	3.81E-10	3.15E-09	8.13E-09	Not detected
	Sep. 30 – Oct. 24	2.03E-09	5.25E-09	1.27E-08	Not detected
	Oct. 24 – Nov. 29	9.01E-10	3.13E-09	8.38E-09	Not detected
	Nov. 29 – Dec. 21	-1.83E-08	1.39E-04	4.54E-08	Not detected
	Dec. 21 – Jan. 6	-1.26E-08	1.84E-08	5.68E-08	Not detected

Table 3-7: Activity concentrations of ^{241}Am in the filter samples collected from Cactus Flats Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{241}Am	Jan. 8 – Jan. 27	1.86E-08	8.14E-09	7.16E-09	Detected
	Jan. 27 – Feb. 10	2.01E-08	1.04E-08	1.27E-08	Detected
	Feb. 10 – Feb. 24	1.46E-08	9.84E-09	1.58E-08	Not detected
	Feb. 24 – Mar. 9	6.18E-08	1.22E-07	1.72E-08	Detected
	Mar. 9 – Mar. 23	1.79E-08	9.34E-09	9.78E-09	Detected
	Mar. 23 – Apr. 6	1.58E-08	1.03E-08	1.67E-08	Not detected
	Apr. 6 – Apr. 26	2.81E-09	4.87E-09	1.11E-08	Not detected
	Apr. 26 – May 9	1.35E-08	9.70E-09	1.59E-08	Not detected
	May 9 – May 25	1.26E-08	9.47E-09	1.79E-08	Not detected
	May 25 – Jun. 16	7.69E-09	5.10E-09	6.48E-09	Detected
	Jun. 16 – Jul. 8	5.70E-09	8.88E-09	1.99E-08	Not detected
	Jul. 8 – Jul. 20	1.88E-08	1.40E-08	2.51E-08	Not detected
	Jul. 20 – Jul. 27*	1.13E-07	6.06E-08	8.40E-08	Detected
	Jul. 27 - Aug. 23	6.47E-09	6.11E-09	1.22E-08	Not detected
	Aug. 23 – Sep. 30	9.30E-09	9.88E-09	1.86E-08	Not detected
	Sep. 30 – Oct. 24	5.33E-09	6.40E-09	1.40E-08	Not detected
	Oct. 24 – Nov. 29	8.64E-09	8.96E-09	1.74E-08	Not detected
	Nov. 29 – Dec. 21	7.54E-09	6.06E-09	1.01E-08	Not detected
	Dec. 21 – Jan. 6	5.06E-09	7.57E-09	1.48E-08	Not detected

* low flow rate and mass loading; use values with caution

Table 3-8: Activity concentrations of $^{239+240}Pu$ in the filter samples collected from Cactus Flats Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
$^{239+240}Pu$	Jan. 8 – Jan. 27	3.79E-09	9.12E-09	2.20E-09	Detected
	Jan. 27 – Feb. 10	8.72E-09	1.38E-08	3.07E-08	Not detected
	Feb. 10 – Feb. 24	1.21E-08	1.04E-08	1.93E-08	Not detected
	Feb. 24 – Mar. 9	7.87E-09	1.14E-08	2.50E-08	Not detected
	Mar. 9 – Mar. 23	2.29E-08	1.23E-08	1.70E-08	Detected
	Mar. 23 – Apr. 6	2.09E-08	1.24E-08	1.67E-08	Detected
	Apr. 6 – Apr. 26	4.76E-09	5.52E-09	1.59E-08	Not detected
	Apr. 26 – May 9	2.73E-08	1.30E-08	1.49E-08	Detected
	May 9 – May 25	4.95E-09	9.24E-09	2.16E-08	Not detected
	May 25 – Jun. 16	9.55E-09	9.31E-09	1.95E-08	Not detected
	Jun. 16 – Jul. 8	1.72E-09	9.77E-09	2.43E-08	Not detected
	Jul. 8 – Jul. 20	1.33E-08	1.38E-08	2.67E-08	Not detected

Table 3-8: Activity concentrations of $^{239+240}$Pu in the filter samples collected from Cactus Flats Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
$^{239+240}$Pu	Jul. 20 – Jul. 27*	2.00E-08	5.69E-08	1.41E-07	Not detected
	Jul. 27 - Aug. 23	1.05E-08	6.82E-09	1.06E-08	Not detected
	Aug. 23 – Sep. 30	2.35E-09	3.32E-09	7.05E-09	Not detected
	Sep. 30 – Oct. 24	6.40E-09	5.53E-09	9.99E-09	Not detected
	Oct. 24 – Nov. 29	5.58E-09	3.98E-09	6.54E-09	Not detected
	Nov. 29 – Dec. 21	2.38E-08	1.91E-08	3.43E-08	Not detected
	Dec. 21 – Jan. 6	5.71E-09	9.92E-09	2.27E-08	Not detected

*low flow rate and mass loading; use values with caution

Table 3-9: Activity concentrations of ^{238}Pu in the filter samples collected from Cactus Flats Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{238}Pu	Jan. 8 – Jan. 27	1.26E-09	4.38E-09	1.17E-08	Not detected
	Jan. 27 – Feb. 10	6.54E-09	1.31E-08	3.07E-08	Not detected
	Feb. 10 – Feb. 24	-4.87E-09	8.45E-09	2.59E-08	Not detected
	Feb. 24 – Mar. 9	-3.14E-09	6.31E-09	2.22E-08	Not detected
	Mar. 9 – Mar. 23	1.21E-09	9.34E-09	2.42E-08	Not detected
	Mar. 23 – Apr. 6	6.99E-09	9.32E-09	1.97E-08	Not detected
	Apr. 6 – Apr. 26	-2.38E-09	5.27E-09	1.59E-08	Not detected
	Apr. 26 – May 9	4.97E-09	9.89E-09	2.33E-07	Not detected
	May 9 – May 25	-1.24E-09	6.56E-09	1.96E-08	Not detected
	May 25 – Jun. 16	2.39E-09	4.78E-09	1.12E-08	Not detected
	Jun. 16 – Jul. 8	-2.59E-09	6.23E-09	1.84E-08	Not detected
	Jul. 8 – Jul. 20	-1.90E-09	6.57E-09	2.27E-09	Not detected
	Jul. 20 – Jul. 27*	4.00E-08	5.69E-08	1.20E-07	Not detected
	Jul. 27 - Aug. 23	7.49E-10	3.36E-09	9.03E-09	Not detected
	Aug. 23 – Sep. 30	-4.10E-09	4.26E-09	1.38E-08	Not detected
	Sep. 30 – Oct. 24	-4.26E-09	4.94E-09	1.59E-08	Not detected
	Oct. 24 – Nov. 29	-3.25E-09	3.37E-09	1.09E-08	Not detected
	Nov. 29 – Dec. 21	-2.17E-09	1.44E-08	4.07E-08	Not detected
	Dec. 21 – Jan. 6	0.00E+00	1.07E-08	2.87E-08	Not detected

*low flow rate and mass loading; use values with caution

Table 3-10: Activity density of ^{241}Am in the filter samples collected from Onsite Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc.(2σ) Bq/g	MDC Bq/g	Status
^{241}Am	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	5.71E-04	3.29E-04	5.03E-04	Detected
	Feb. 24 – Mar. 9	5.75E-04	3.56E-04	5.69E-04	Detected
	Mar. 9 – Mar. 23	3.96E-04	2.45E-04	4.06E-04	Not detected
	Mar. 23 – Apr. 6	7.76E-05	2.61E-04	2.16E-04	Not detected
	Apr. 6 – Apr. 26	7.38E-04	3.49E-04	4.68E-04	Detected
	Apr. 26 – May 9	3.89E-04	1.91E-04	2.23E-04	Detected
	May 9 – May 25	2.76E-04	2.18E-04	4.21E-04	Not detected
	May 25 – Jun. 16	8.09E-04	2.76E-04	2.85E-04	Detected
	Jun. 16 – Jul. 8	1.01E-03	3.72E-04	3.39E-04	Detected
	Jul. 8 – Jul. 20	5.15E-04	3.07E-04	5.11E-04	Detected
	Jul. 20 – Jul. 27	2.10E-03	7.82E-04	1.00E-03	Detected
	Jul. 27 - Aug. 23	5.54E-04	2.50E-04	3.44E-04	Detected
	Aug. 23 – Sep. 30	1.47E-03	3.81E-04	2.69E-04	Detected
	Sep. 30 – Oct. 24	4.71E-04	2.18E-04	3.41E-04	Detected
	Oct. 24 – Nov. 29	7.04E-04	2.64E-04	1.98E-04	Detected
	Nov. 29 – Dec. 21	1.17E-04	1.54E-04	3.35E-04	Not detected
	Dec. 21 – Jan. 6	5.66E-04	4.90E-04	9.80E-04	Not detected

Table 3-11: Activity Density of $^{239+240}Pu$ in the filter samples collected from Onsite Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
$^{239+240}Pu$	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	4.77E-05	1.35E-04	3.51E-04	Not detected
	Feb. 24 – Mar. 9	5.56E-04	5.16E-04	9.81E-04	Not detected
	Mar. 9 – Mar. 23	6.04E-04	3.48E-04	5.53E-04	Detected
	Mar. 23 – Apr. 6	8.06E-05	2.21E-04	2.21E-04	Not detected
	Apr. 6 – Apr. 26	3.57E-04	2.87E-04	3.77E-04	Not detected
	Apr. 26 – May 9	2.83E-04	1.82E-04	2.62E-04	Detected
	May 9 – May 25	4.31E-04	2.89E-04	5.07E-04	Not detected
	May 25 – Jun. 16	6.33E-05	2.43E-04	5.95E-04	Not detected
	Jun. 16 – Jul. 8	4.64E-04	2.26E-04	2.66E-04	Detected
	Jul. 8 – Jul. 20	3.77E-04	2.81E-04	5.04E-04	Not detected

*sampler was offline due to power outage

Table 3-11: Activity density of $^{239+240}Pu$ in the filter samples collected from Onsite Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
$^{239+240}Pu$	Jul. 20 – Jul. 27	6.67E-04	5.60E-04	1.05E-03	Not detected
	Jul. 27 - Aug. 23	8.84E-05	1.66E-04	3.85E-04	Not detected
	Aug. 23 – Sep. 30	4.79E-04	2.34E-04	2.74E-04	Detected
	Sep. 30 – Oct. 24	2.78E-04	1.85E-04	3.26E-04	Not detected
	Oct. 24 – Nov. 29	1.84E-04	2.86E-04	6.41E-04	Not detected
	Nov. 29 – Dec. 21	2.26E-04	2.82E-04	5.96E-04	Not detected
	Dec. 21 – Jan. 6	-2.58E-04	5.18E-04	1.62E-03	Not detected

*sampler was offline due to power outage

Table 3-12: Activity density of ^{238}Pu in the filter samples collected from Onsite Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{238}Pu	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	4.77E-05	1.35E-04	3.51E-04	Not detected
	Feb. 24 – Mar. 9	0.00E+00	1.75E-04	5.75E-04	Not detected
	Mar. 9 – Mar. 23	0.00E+00	1.80E-04	5.03E-04	Not detected
	Mar. 23 – Apr. 6	1.04E-11	1.24E-04	3.47E-04	Not detected
	Apr. 6 – Apr. 26	-1.19E-04	1.96E-04	5.82E-04	Not detected
	Apr. 26 – May 9	-6.55E-05	1.16E-04	3.79E-04	Not detected
	May 9 – May 25	-4.80E-05	9.34E-05	3.23E-04	Not detected
	May 25 – Jun. 16	-8.45E-05	1.34E-04	4.25E-04	Not detected
	Jun. 16 – Jul. 8	-1.98E-04	2.30E-04	6.77E-04	Not detected
	Jul. 8 – Jul. 20	5.78E-05	1.64E-04	4.07E-04	Not detected
	Jul. 20 – Jul. 27	6.03E-05	3.20E-04	8.53E-04	Not detected
	Jul. 27 - Aug. 23	-2.21E-05	9.90E-05	3.12E-04	Not detected
	Aug. 23 – Sep. 30	-4.57E-05	2.66E-04	6.99E-04	Not detected
	Sep. 30 – Oct. 24	-8.66E-05	1.04E-04	3.48E-04	Not detected
	Oct. 24 – Nov. 29	7.35E-05	1.80E-04	4.42E-04	Not detected
	Nov. 29 – Dec. 21	-3.76E-05	2.49E-04	7.07E-04	Not detected
	Dec. 21 – Jan. 6	-7.73E-04	7.13E-04	2.27E-03	Not detected

*sampler was offline due to power outage

Table 3-13: Activity density of ^{241}Am in the filter samples collected from Near Field Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{241}Am	Jan. 8 – Jan. 27	1.48E-03	5.46E-04	4.03E-04	Detected
	Jan. 27 – Feb. 10	4.74E-04	2.90E-04	2.95E-04	Detected
	Feb. 10 – Feb. 24	6.23E-04	4.44E-04	6.82E-04	Not detected
	Feb. 24 – Mar. 9	1.69E-04	2.80E-04	6.37E-04	Not detected
	Mar. 9 – Mar. 23	2.88E-04	2.17E-04	3.70E-04	Not detected
	Mar. 23 – Apr. 6	3.14E-04	2.18E-04	3.94E-04	Not detected
	Apr. 6 – Apr. 26	2.62E-04	1.61E-04	2.26E-04	Detected
	Apr. 26 – May 9	7.57E-04	6.13E-04	1.01E-03	Not detected
	May 9 – May 25	3.52E-04	2.38E-04	4.09E-04	Not detected
	May 25 – Jun. 16	1.94E-04	1.89E-04	3.75E-04	Not detected
	Jun. 16 – Jul. 8	2.98E-04	2.08E-04	2.77E-04	Detected
	Jul. 8 – Jul. 20	3.50E-04	2.82E-04	5.42E-04	Not detected
	Jul. 20 – Jul. 27	4.99E-04	5.91E-04	1.24E-03	Not detected
	Jul. 27 - Aug. 23	3.63E-04	2.09E-04	3.01E-04	Detected
	Aug. 23 – Sep. 30	3.27E-04	1.95E-04	2.88E-04	Detected
	Sep. 30 – Oct. 24	3.50E-05	1.92E-04	4.79E-04	Not detected
	Oct. 24 – Nov. 29	2.52E-04	1.41E-04	2.20E-04	Detected
	Nov. 29 – Dec. 21	3.75E-05	1.68E-04	4.22E-04	Not detected
	Dec. 21 – Jan. 6	4.63E-04	5.17E-04	1.10E-03	Not detected

Table 3-14: Activity Density of $^{239+240}$Pu in the filter samples collected from Near Field Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
$^{239+240}$Pu	Jan. 8 – Jan. 27	8.87E-04	5.08E-04	7.34E-04	Detected
	Jan. 27 – Feb. 10	4.57E-04	4.36E-04	7.08E-04	Not detected
	Feb. 10 – Feb. 24	1.63E-04	4.90E-04	9.79E-04	Not detected
	Feb. 24 – Mar. 9	1.48E-04	3.57E-04	8.61E-04	Not detected
	Mar. 9 – Mar. 23	-2.80E-05	3.30E-04	8.55E-04	Not detected
	Mar. 23 – Apr. 6	1.99E-04	2.25E-04	4.70E-04	Not detected
	Apr. 6 – Apr. 26	1.43E-04	2.53E-04	5.83E-04	Not detected
	Apr. 26 – May 9	3.77E-04	2.19E-04	2.51E-04	Detected
	May 9 – May 25	1.79E-04	2.89E-04	6.62E-04	Not detected
	May 25 – Jun. 16	2.14E-04	2.57E-04	5.58E-04	Not detected
	Jun. 16 – Jul. 8	1.10E-04	2.06E-04	4.78E-04	Not detected
	Jul. 8 – Jul. 20	4.51E-04	3.56E-04	6.88E-04	Not detected
	Jul. 20 – Jul. 27	1.14E-10	9.55E-04	2.55E-03	Not detected
	Jul. 27 - Aug. 23	2.84E-04	2.53E-04	5.06E-04	Not detected
	Aug. 23 – Sep. 30	1.93E-04	1.98E-04	4.13E-04	Not detected

Table 3-14: Activity density of $^{239+240}$Pu in the filter samples collected from Near Field Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
$^{239+240}$Pu	Sep. 30 – Oct. 24	1.03E-04	2.24E-04	5.28E-04	Not detected
	Oct. 24 – Nov. 29	5.15E-04	2.96E-04	4.27E-04	Detected
	Nov. 29 – Dec. 21	4.57E-04	3.98E-04	7.17E-04	Not detected
	Dec. 21 – Jan. 6	1.34E-03	1.17E-03	2.10E-03	Not detected

Table 3-15: Activity density of ^{238}Pu in the filter samples collected from Near Field Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{238}Pu	Jan. 8 – Jan. 27	-1.04E-04	2.09E-04	7.34E-04	Not detected
	Jan. 27 – Feb. 10	-1.53E-04	3.75E-04	1.21E-03	Not detected
	Feb. 10 – Feb. 24	4.07E-04	4.90E-04	9.79E-04	Not detected
	Feb. 24 – Mar. 9	4.93E-05	2.21E-04	5.95E-04	Not detected
	Mar. 9 – Mar. 23	-2.80E-05	2.15E-04	5.96E-04	Not detected
	Mar. 23 – Apr. 6	1.19E-11	1.23E-04	3.52E-04	Not detected
	Apr. 6 – Apr. 26	2.38E-05	1.58E-04	4.13E-04	Not detected
	Apr. 26 – May 9	-6.45E-12	1.08E-04	3.25E-04	Not detected
	May 9 – May 25	-2.95E-05	1.32E-04	4.16E-04	Not detected
	May 25 – Jun. 16	9.50E-05	1.51E-04	3.36E-04	Not detected
	Jun. 16 – Jul. 8	5.21E-05	1.48E-04	3.67E-04	Not detected
	Jul. 8 – Jul. 20	1.30E-04	2.62E-04	6.11E-04	Not detected
	Jul. 20 – Jul. 27	-3.94E-11	4.04E-04	1.17E-03	Not detected
	Jul. 27 - Aug. 23	-1.13E-11	1.16E-04	3.35E-04	Not detected
	Aug. 23 – Sep. 30	1.93E-05	1.60E-04	4.13E-04	Not detected
	Sep. 30 – Oct. 24	6.20E-05	1.61E-04	3.89E-04	Not detected
	Oct. 24 – Nov. 29	3.02E-05	1.05E-04	2.81E-04	Not detected
	Nov. 29 – Dec. 21	-5.59E-04	4.24E+00	1.39E-03	Not detected
	Dec. 21 – Jan. 6	-7.44E-04	1.08E-03	3.34E-03	Not detected

Table 3-16: Activity density of ^{241}Am in the filter samples collected from Cactus Flats Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{241}Am	Jan. 8 – Jan. 27	8.73E-04	3.83E-04	3.37E-04	Detected
	Jan. 27 – Feb. 10	6.21E-04	3.22E-04	3.92E-04	Detected
	Feb. 10 – Feb. 24	4.10E-04	2.77E-04	4.44E-04	Not detected
	Feb. 24 – Mar. 9	1.81E-03	3.56E-03	5.03E-04	Detected
	Mar. 9 – Mar. 23	5.17E-04	2.70E-04	2.82E-04	Detected
	Mar. 23 – Apr. 6	3.47E-04	2.25E-04	3.66E-04	Not detected
	Apr. 6 – Apr. 26	1.09E-04	1.89E-04	4.31E-04	Not detected
	Apr. 26 – May 9	2.96E-04	2.13E-04	3.48E-04	Not detected
	May 9 – May 25	3.49E-04	2.61E-04	4.95E-04	Not detected
	May 25 – Jun. 16	2.39E-04	1.58E-04	2.01E-04	Detected
	Jun. 16 – Jul. 8	2.09E-04	3.26E-04	7.28E-04	Not detected
	Jul. 8 – Jul. 20	4.81E-04	3.59E-04	6.43E-04	Not detected
	Jul. 20 – Jul. 27*	4.14E-03	2.21E-03	3.07E-03	Detected
	Jul. 27 - Aug. 23	1.87E-04	1.76E-04	3.52E-04	Not detected
	Aug. 23 – Sep. 30	4.77E-04	5.07E-04	9.56E-04	Not detected
	Sep. 30 – Oct. 24	1.64E-04	1.97E-04	4.31E-04	Not detected
	Oct. 24 – Nov. 29	3.17E-04	3.29E-04	6.39E-04	Not detected
	Nov. 29 – Dec. 21	2.28E-04	1.83E-04	3.04E-04	Not detected
	Dec. 21 – Jan. 6	2.63E-04	3.93E-04	7.66E-04	Not detected

*low flow rate and mass loading; use values with caution

Table 3-17: Activity Density of $^{239+240}Pu$ in the filter samples collected from Cactus Flats Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
$^{239+240}Pu$	Jan. 8 – Jan. 27	1.78E-04	4.29E-04	1.04E-04	Detected
	Jan. 27 – Feb. 10	2.69E-04	4.25E-04	9.48E-04	Not detected
	Feb. 10 – Feb. 24	3.41E-04	2.91E-04	5.43E-04	Not detected
	Feb. 24 – Mar. 9	2.30E-04	3.33E-04	7.30E-04	Not detected
	Mar. 9 – Mar. 23	6.62E-04	3.56E-04	4.91E-04	Detected
	Mar. 23 – Apr. 6	4.59E-04	2.72E-04	3.66E-04	Detected
	Apr. 6 – Apr. 26	1.84E-04	2.14E-04	6.18E-04	Not detected
	Apr. 26 – May 9	5.98E-04	2.85E-04	3.27E-04	Detected
	May 9 – May 25	1.37E-04	2.55E-04	5.95E-04	Not detected
	May 25 – Jun. 16	2.96E-04	2.89E-04	6.05E-04	Not detected
	Jun. 16 – Jul. 8	6.32E-05	3.58E-04	8.92E-04	Not detected
	Jul. 8 – Jul. 20	3.39E-04	3.52E-04	6.82E-04	Not detected
	Jul. 20 – Jul. 27*	7.30E-04	2.08E-03	5.15E-03	Not detected
	Jul. 27 - Aug. 23	3.03E-04	1.97E-04	3.05E-04	Not detected

Table 3-17: Activity density of $^{239+240}$Pu in the filter samples collected from Cactus Flats Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
$^{239+240}$Pu	Aug. 23 – Sep. 30	1.21E-04	1.70E-04	3.62E-04	Not detected
	Sep. 30 – Oct. 24	1.97E-04	1.70E-04	3.07E-04	Not detected
	Oct. 24 – Nov. 29	2.05E-04	1.46E-04	2.40E-04	Not detected
	Nov. 29 – Dec. 21	7.21E-04	5.77E-04	1.04E-03	Not detected
	Dec. 21 – Jan. 6	2.97E-04	5.15E-04	1.18E-03	Not detected

*low flow rate and mass loading; use values with caution.

Table 3-18: Activity density of ^{238}Pu in the filter samples collected from Cactus Flats Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{238}Pu	Jan. 8 – Jan. 27	5.94E-05	2.06E-04	5.51E-04	Not detected
	Jan. 27 – Feb. 10	2.02E-04	4.03E-04	9.48E-04	Not detected
	Feb. 10 – Feb. 24	-1.37E-04	2.37E-04	7.28E-04	Not detected
	Feb. 24 – Mar. 9	-9.19E-05	1.84E-04	6.48E-04	Not detected
	Mar. 9 – Mar. 23	3.49E-05	2.70E-04	7.00E-04	Not detected
	Mar. 23 – Apr. 6	1.53E-04	2.04E-04	4.32E-04	Not detected
	Apr. 6 – Apr. 26	-9.22E-05	2.04E-04	6.18E-04	Not detected
	Apr. 26 – May 9	1.09E-04	2.17E-04	5.10E-03	Not detected
	May 9 – May 25	-3.42E-05	1.81E-04	5.42E-04	Not detected
	May 25 – Jun. 16	7.41E-05	1.48E-04	3.48E-04	Not detected
	Jun. 16 – Jul. 8	-9.48E-05	2.28E-04	6.74E-04	Not detected
	Jul. 8 – Jul. 20	-4.85E-05	1.68E-04	5.82E-05	Not detected
	Jul. 20 – Jul. 27*	1.46E-03	2.08E-03	4.39E-03	Not detected
	Jul. 27 - Aug. 23	2.16E-05	9.70E-05	2.61E-04	Not detected
	Aug. 23 – Sep.	-2.10E-04	2.19E-04	7.09E-04	Not detected
	Sep. 30 – Oct. 24	-1.31E-04	1.52E-04	4.90E-04	Not detected
	Oct. 24 – Nov. 29	-1.19E-04	1.23E-04	4.00E-04	Not detected
	Nov. 29 – Dec.	-6.55E-05	4.36E-04	1.23E-03	Not detected
	Dec. 21 – Jan. 6	0.00E+00	5.55E-04	1.49E-03	Not detected

*low flow rate and mass loading; use values with caution

Table 3-19: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Onsite station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{234}U	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb.10*	-	-	-	-
	Feb. 10 – Feb. 24	9.89E-07	3.08E-07	5.98E-08	Detected
	Feb. 24 – Mar. 9	1.37E-06	3.00E-07	4.68E-08	Detected
	Mar. 9 – Mar. 23	1.80E-06	3.41E-07	4.51E-08	Detected
	Mar. 23 – Apr. 6	1.91E-06	3.10E-07	2.33E-08	Detected
	Apr. 6 – Apr. 26	1.06E-06	1.94E-07	1.61E-08	Detected
	Apr. 26 – May 9	1.49E-06	2.93E-07	2.64E-08	Detected
	May 9 – May 25	1.08E-06	2.12E-07	4.19E-08	Detected
	May 25 – Jun. 16	1.14E-06	1.92E-07	1.69E-08	Detected
	Jun. 16 – Jul. 8	8.96E-07	1.70E-07	2.50E-08	Detected
	Jul. 8 – Jul. 20	1.58E-06	3.07E-07	2.24E-08	Detected
	Jul. 20 – Jul. 27	2.08E-06	4.61E-07	4.99E-08	Detected
	Jul. 27 - Aug. 23	6.94E-07	1.42E-07	1.42E-08	Detected
	Aug. 23 – Sep. 30	5.19E-07	1.05E-07	2.07E-08	Detected
	Sep. 30 – Oct. 24	9.52E-07	1.71E-07	1.63E-08	Detected
	Oct. 24 – Nov. 29	8.27E-07	1.36E-07	1.09E-08	Detected
	Nov. 29 – Dec. 21	7.97E-07	1.66E-07	2.48E-08	Detected
	Dec. 21 – Jan. 6	1.28E-06	2.53E-07	4.84E-08	Detected
^{235}U	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb.10*	-	-	-	-
	Feb. 10 – Feb. 24	7.86E-08	5.76E-08	5.97E-08	Detected
	Feb. 24 – Mar. 9	1.17E-07	5.04E-08	3.68E-08	Detected
	Mar. 9 – Mar. 23	8.94E-08	4.64E-08	4.82E-08	Detected
	Mar. 23 – Apr. 6	9.56E-08	3.58E-08	2.55E-08	Detected
	Apr. 6 – Apr. 26	5.61E-08	2.40E-08	1.76E-08	Detected
	Apr. 26 – May 9	1.27E-07	4.58E-08	2.14E-08	Detected
	May 9 – May 25	5.84E-08	2.71E-08	2.64E-08	Detected
	May 25 – Jun. 16	7.65E-08	2.37E-08	1.17E-08	Detected
	Jun. 16 – Jul. 8	4.62E-08	2.18E-08	1.85E-08	Detected
	Jul. 8 – Jul. 20	1.41E-07	4.98E-08	3.99E-08	Detected
	Jul. 20 – Jul. 27	2.15E-07	8.12E-08	6.76E-08	Detected
	Jul. 27 - Aug. 23	3.88E-08	1.99E-08	1.92E-08	Detected
	Aug. 23 – Sep. 30	2.63E-08	1.63E-08	2.29E-08	Detected
	Sep. 30 – Oct. 24	4.29E-08	1.95E-08	1.29E-08	Detected
	Oct. 24 – Nov. 29	4.08E-08	1.53E-08	9.23E-09	Detected
	Nov. 29 – Dec. 21	2.35E-08	1.99E-08	1.83E-08	Detected
	Dec. 21 – Jan. 6	1.77E-07	5.42E-08	5.35E-08	Detected

Table 3-19: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Onsite station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{238}U	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb.10*	-	-	-	-
	Feb. 10 – Feb. 24	1.27E-06	3.40E-07	6.87E-08	Detected
	Feb. 24 – Mar. 9	1.17E-06	2.78E-07	5.82E-08	Detected
	Mar. 9 – Mar. 23	1.60E-06	3.18E-07	6.29E-08	Detected
	Mar. 23 – Apr. 6	1.84E-06	3.02E-07	2.06E-08	Detected
	Apr. 6 – Apr. 26	9.60E-07	1.83E-07	2.38E-08	Detected
	Apr. 26 – May 9	1.47E-06	2.91E-07	4.39E-08	Detected
	May 9 – May 25	9.64E-07	1.99E-07	3.70E-08	Detected
	May 25 – Jun. 16	1.12E-06	1.90E-07	1.77E-08	Detected
	Jun. 16 – Jul. 8	9.07E-07	1.71E-07	2.95E-08	Detected
	Jul. 8 – Jul. 20	1.36E-06	2.83E-07	3.73E-08	Detected
	Jul. 20 – Jul. 27	1.79E-06	4.29E-07	5.46E-08	Detected
	Jul. 27 - Aug. 23	6.58E-07	1.38E-07	1.55E-08	Detected
	Aug. 23 – Sep. 30	4.90E-07	1.02E-07	2.12E-08	Detected
	Sep. 30 – Oct. 24	9.57E-07	1.71E-07	2.12E-08	Detected
	Oct. 24 – Nov. 29	7.44E-07	1.27E-07	1.46E-08	Detected
	Nov. 29 – Dec. 21	7.19E-07	1.57E-07	3.13E-08	Detected
	Dec. 21 – Jan. 6	1.15E-06	2.37E-07	4.97E-08	Detected

*sampler was offline due to power outage

Table 3-20: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Near Field Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{234}U	Jan. 8 – Jan. 27	7.29E-07	1.66E-07	3.03E-08	Detected
	Jan. 27 – Feb.10	9.15E-07	2.44E-07	5.37E-08	Detected
	Feb. 10 – Feb. 24	9.01E-07	2.29E-07	3.41E-08	Detected
	Feb. 24 – Mar. 9	1.07E-06	2.44E-07	3.61E-08	Detected
	Mar. 9 – Mar. 23	1.30E-06	2.77E-07	5.30E-08	Detected
	Mar. 23 – Apr. 6	1.80E-06	3.21E-07	3.24E-08	Detected
	Apr. 6 – Apr. 26	1.27E-06	2.23E-07	2.38E-08	Detected
	Apr. 26 – May 9	2.02E-06	3.50E-07	2.46E-08	Detected
	May 9 – May 25	1.38E-06	2.47E-07	1.59E-08	Detected
	May 25 – Jun. 16	1.11E-06	2.02E-07	1.23E-08	Detected
	Jun. 16 – Jul. 8	9.31E-07	1.74E-07	1.50E-08	Detected
	Jul. 8 – Jul. 20	1.65E-06	3.08E-07	1.94E-08	Detected
	Jul. 20 – Jul. 27	1.15E-06	3.43E-07	4.44E-08	Detected

Table 3-20: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Near Field Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{234}U	Jul. 27 - Aug. 23	7.44E-07	1.40E-07	1.15E-08	Detected
	Aug. 23 – Sep. 30	4.20E-07	8.67E-08	9.63E-09	Detected
	Sep. 30 – Oct. 24	6.80E-07	1.45E-07	1.96E-08	Detected
	Oct. 24 – Nov. 29	7.65E-07	1.31E-07	1.18E-08	Detected
	Nov. 29 – Dec. 21	1.14E-06	2.01E-07	2.02E-08	Detected
	Dec. 21 – Jan. 6	7.43E-07	1.72E-07	1.67E-08	Detected
^{235}U	Jan. 8 – Jan. 27	6.73E-08	2.82E-08	1.47E-08	Detected
	Jan. 27 – Feb. 10	1.19E-07	5.34E-08	4.64E-08	Detected
	Feb. 10 – Feb. 24	8.13E-08	4.13E-08	3.18E-08	Detected
	Feb. 24 – Mar. 9	1.76E-05	3.44E-05	3.35E-05	Not detected
	Mar. 9 – Mar. 23	2.96E-08	3.73E-08	5.68E-08	Not detected
	Mar. 23 – Apr. 6	1.20E-07	4.45E-08	3.71E-08	Detected
	Apr. 6 – Apr. 26	7.27E-08	2.76E-08	2.30E-08	Detected
	Apr. 26 – May 9	1.01E-07	4.05E-08	1.58E-08	Detected
	May 9 – May 25	7.64E-08	3.07E-08	1.52E-08	Detected
	May 25 – Jun. 16	4.50E-08	2.20E-08	9.31E-09	Detected
	Jun. 16 – Jul. 8	6.27E-08	2.40E-08	1.65E-08	Detected
	Jul. 8 – Jul. 20	1.35E-07	4.52E-08	2.82E-08	Detected
	Jul. 20 – Jul. 27	2.37E-08	4.56E-08	4.88E-08	Not detected
	Jul. 27 - Aug. 23	3.36E-08	1.65E-08	1.26E-08	Detected
	Aug. 23 – Sep. 30	1.97E-08	1.15E-08	1.08E-08	Detected
	Sep. 30 – Oct. 24	1.64E-08	1.74E-08	2.04E-08	Not detected
	Oct. 24 – Nov. 29	2.41E-08	1.32E-08	1.00E-08	Detected
	Nov. 29 – Dec. 21	3.85E-08	2.22E-08	2.31E-08	Detected
	Dec. 21 – Jan. 6	4.21E-08	2.29E-08	1.20E-08	Detected
^{238}U	Jan. 8 – Jan. 27	6.96E-07	1.63E-07	3.14E-08	Detected
	Jan. 27 – Feb. 10	8.88E-07	2.40E-07	5.34E-08	Detected
	Feb. 10 – Feb. 24	9.46E-07	2.33E-07	4.03E-08	Detected
	Feb. 24 – Mar. 9	9.42E-07	2.29E-07	3.33E-08	Detected
	Mar. 9 – Mar. 23	1.24E-06	2.72E-07	8.08E-08	Detected
	Mar. 23 – Apr. 6	1.83E-06	3.23E-07	3.45E-08	Detected
	Apr. 6 – Apr. 26	1.29E-06	2.24E-07	3.13E-08	Detected
	Apr. 26 – May 9	1.89E-06	3.36E-07	3.90E-08	Detected
	May 9 – May 25	1.35E-06	2.44E-07	3.10E-08	Detected
	May 25 – Jun. 16	1.06E-06	1.96E-07	2.29E-08	Detected
	Jun. 16 – Jul. 8	9.02E-07	1.71E-07	2.41E-08	Detected

Table 3-20: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Near Field Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{238}U	Jul. 8 – Jul. 20	1.45E-06	2.86E-07	3.62E-08	Detected
	Jul. 20 – Jul. 27	1.11E-06	3.40E-07	4.86E-08	Detected
	Jul. 27 - Aug. 23	7.15E-07	1.37E-07	1.26E-08	Detected
	Aug. 23 – Sep. 30	3.53E-07	7.93E-08	1.29E-08	Detected
	Sep. 30 – Oct. 24	6.34E-07	1.39E-07	1.65E-08	Detected
	Oct. 24 – Nov. 29	6.74E-07	1.21E-07	1.58E-08	Detected
	Nov. 29 – Dec. 21	9.96E-07	1.85E-07	3.35E-08	Detected
	Dec. 21 – Jan. 6	7.11E-07	1.69E-07	2.35E-08	Detected

Table 3-21: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Cactus Flats Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{234}U	Jan. 8 – Jan. 27	8.03E-07	1.74E-07	2.19E-08	Detected
	Jan. 27 – Feb. 10	1.16E-06	2.53E-07	3.97E-08	Detected
	Feb. 10 – Feb. 24	1.12E-06	2.48E-07	3.82E-08	Detected
	Feb. 24 – Mar. 9	1.02E-06	2.32E-07	3.52E-08	Detected
	Mar. 9 – Mar. 23	1.32E-06	2.76E-07	4.63E-08	Detected
	Mar. 23 – Apr. 6	1.26E-06	2.59E-07	3.29E-08	Detected
	Apr. 6 – Apr. 26	1.05E-06	1.93E-07	2.08E-08	Detected
	Apr. 26 – May 9	2.26E-06	3.66E-07	2.56E-08	Detected
	May 9 – May 25	1.27E-06	2.32E-07	2.14E-08	Detected
	May 25 – Jun. 16	1.14E-06	1.97E-07	1.61E-08	Detected
	Jun. 16 – Jul. 8	9.86E-07	1.88E-07	2.48E-08	Detected
	Jul. 8 – Jul. 20	1.62E-06	3.35E-07	2.94E-08	Detected
	Jul. 20 – Jul. 27*	2.19E-06	9.04E-07	1.62E-07	Detected
	Jul. 27 - Aug. 23	1.08E-06	1.81E-07	1.41E-08	Detected
	Aug. 23 – Sep. 30	5.01E-07	6.92E-08	1.56E-08	Detected
	Sep. 30 – Oct. 24	8.06E-07	1.53E-07	1.49E-08	Detected
	Oct. 24 – Nov. 29	1.03E-06	1.85E-07	2.80E-08	Detected
	Nov. 29 – Dec. 21	1.14E-06	2.01E-07	2.53E-08	Detected
	Dec. 21 – Jan. 6	6.94E-07	1.68E-07	2.08E-08	Detected
^{235}U	Jan. 8 – Jan. 27	5.25E-08	2.59E-08	1.87E-08	Detected
	Jan. 27 – Feb. 10	5.27E-08	3.45E-08	2.92E-08	Detected
	Feb. 10 – Feb. 24	5.07E-08	3.46E-08	3.01E-08	Detected
	Feb. 24 – Mar. 9	6.15E-08	3.52E-08	2.77E-08	Detected

Table 3-21: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Cactus Flats Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{235}U	Mar. 9 – Mar. 23	6.58E-08	3.92E-08	3.77E-08	Detected
	Mar. 23 – Apr. 6	1.68E-07	5.23E-08	3.69E-08	Detected
	Apr. 6 – Apr. 26	3.38E-08	2.01E-08	1.19E-08	Detected
	Apr. 26 – May 9	1.30E-07	4.29E-08	1.46E-08	Detected
	May 9 – May 25	6.29E-08	2.78E-08	2.23E-08	Detected
	May 25 – Jun. 16	1.15E-07	3.04E-08	8.39E-09	Detected
	Jun. 16 – Jul. 8	4.00E-08	2.16E-08	1.21E-08	Detected
	Jul. 8 – Jul. 20	1.41E-07	5.22E-08	2.39E-08	Detected
	Jul. 20 – Jul. 27*	9.80E-08	1.37E-07	9.83E-08	Not detected
	Jul. 27 - Aug. 23	4.96E-08	1.90E-08	8.62E-09	Detected
	Aug. 23 – Sep. 30	7.94E-09	1.15E-08	1.57E-08	Not detected
	Sep. 30 – Oct. 24	3.47E-08	1.88E-08	1.83E-08	Detected
	Oct. 24 – Nov. 29	3.97E-08	2.25E-08	1.70E-08	Detected
	Nov. 29 – Dec.	5.47E-08	2.37E-08	1.80E-08	Detected
	Dec. 21 – Jan. 6	2.15E-08	2.04E-08	1.63E-08	Detected
^{238}U	Jan. 8 – Jan. 27	7.24E-07	1.66E-07	3.43E-08	Detected
	Jan. 27 – Feb. 10	1.04E-06	2.39E-07	3.42E-08	Detected
	Feb. 10 – Feb. 24	1.07E-06	2.42E-07	3.52E-08	Detected
	Feb. 24 – Mar. 9	1.07E-06	2.31E-07	4.19E-08	Detected
	Mar. 9 – Mar. 23	1.19E-06	2.62E-07	6.95E-08	Detected
	Mar. 23 – Apr. 6	1.44E-06	2.80E-07	2.98E-08	Detected
	Apr. 6 – Apr. 26	1.01E-06	1.89E-07	2.63E-08	Detected
	Apr. 26 – May 9	1.99E-06	3.38E-07	3.02E-08	Detected
	May 9 – May 25	1.11E-06	2.14E-07	2.89E-08	Detected
	May 25 – Jun. 16	1.07E-06	1.90E-07	1.60E-08	Detected
	Jun. 16 – Jul. 8	9.85E-07	1.88E-07	2.68E-08	Detected
	Jul. 8 – Jul. 20	1.60E-06	3.32E-07	4.18E-08	Detected
	Jul. 20 – Jul. 27*	2.46E-06	9.36E-07	1.49E-07	Detected
	Jul. 27 - Aug. 23	1.01E-06	1.72E-07	1.30E-08	Detected
	Aug. 23 – Sep. 30	4.01E-07	8.97E-08	1.37E-08	Detected
	Sep. 30 – Oct. 24	7.95E-07	1.52E-07	1.35E-08	Detected
	Oct. 24 – Nov. 29	9.08E-07	2.25E-08	1.70E-08	Detected
	Nov. 29 – Dec.	9.73E-07	2.37E-08	1.80E-08	Detected
	Dec. 21 – Jan. 6	6.94E-07	2.04E-08	1.63E-08	Detected

*low flow rate and mass loading; use values with caution

Table 3-22: Activity density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Onsite Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{234}U	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	
	Feb. 10 – Feb. 24	2.04E-02	6.34E-03	1.23E-03	Detected
	Feb. 24 – Mar. 9	4.16E-02	9.13E-03	1.42E-03	Detected
	Mar. 9 – Mar. 23	3.55E-02	6.72E-03	8.89E-04	Detected
	Mar. 23 – Apr. 6	3.74E-02	6.06E-03	4.55E-04	Detected
	Apr. 6 – Apr. 26	3.17E-02	5.80E-03	4.81E-04	Detected
	Apr. 26 – May 9	2.43E-02	4.79E-03	4.32E-04	Detected
	May 9 – May 25	2.65E-02	5.19E-03	1.02E-03	Detected
	May 25 – Jun. 16	3.13E-02	5.28E-03	4.65E-04	Detected
	Jun. 16 – Jul. 8	2.92E-02	5.56E-03	8.16E-04	Detected
	Jul. 8 – Jul. 20	3.52E-02	6.86E-03	4.99E-04	Detected
	Jul. 20 – Jul. 27	4.57E-02	1.01E-02	1.10E-03	Detected
	Jul. 27 - Aug. 23	2.30E-02	4.72E-03	4.72E-04	Detected
	Aug. 23 – Sep.	2.52E-02	5.10E-03	1.00E-03	Detected
	Sep. 30 – Oct. 24	2.50E-02	4.49E-03	4.30E-04	Detected
	Oct. 24 – Nov. 29	2.80E-02	4.62E-03	3.68E-04	Detected
	Nov. 29 – Dec.	2.25E-02	4.69E-03	6.97E-04	Detected
	Dec. 21 – Jan. 6	6.66E-02	1.31E-02	2.51E-03	Detected
^{235}U	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	--	-
	Feb. 10 – Feb. 24	1.62E-03	1.19E-03	1.23E-03	Detected
	Feb. 24 – Mar. 9	3.55E-03	1.53E-03	1.12E-03	Detected
	Mar. 9 – Mar. 23	1.76E-03	9.15E-04	9.50E-04	Detected
	Mar. 23 – Apr. 6	1.87E-03	7.00E-04	4.98E-04	Detected
	Apr. 6 – Apr. 26	1.68E-03	7.17E-04	5.27E-04	Detected
	Apr. 26 – May 9	2.08E-03	7.49E-04	3.50E-04	Detected
	May 9 – May 25	1.43E-03	6.64E-04	6.47E-04	Detected
	May 25 – Jun. 16	2.10E-03	6.52E-04	3.22E-04	Detected
	Jun. 16 – Jul. 8	1.51E-03	7.11E-04	6.04E-04	Detected
	Jul. 8 – Jul. 20	3.15E-03	1.11E-03	8.90E-04	Detected
	Jul. 20 – Jul. 27	4.71E-03	1.78E-03	1.48E-03	Detected
	Jul. 27 - Aug. 23	1.29E-03	6.59E-04	6.39E-04	Detected
	Aug. 23 – Sep.	1.28E-03	7.90E-04	1.11E-03	Detected
	Sep. 30 – Oct. 24	1.13E-03	5.14E-04	3.38E-04	Detected
	Oct. 24 – Nov. 29	1.38E-03	5.19E-04	3.13E-04	Detected
	Nov. 29 – Dec.	6.62E-04	5.61E-04	5.14E-04	Detected
	Dec. 21 – Jan. 6	9.19E-03	2.81E-03	2.78E-03	Detected

*sampler was offline due to power outage

Table 3-22: Activity density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Onsite Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{238}U	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	2.61E-02	7.00E-03	1.41E-03	Detected
	Feb. 24 – Mar. 9	3.57E-02	8.44E-03	1.77E-03	Detected
	Mar. 9 – Mar. 23	3.16E-02	6.28E-03	1.24E-03	Detected
	Mar. 23 – Apr. 6	3.59E-02	5.90E-03	4.02E-04	Detected
	Apr. 6 – Apr. 26	2.87E-02	5.47E-03	7.10E-04	Detected
	Apr. 26 – May 9	2.40E-02	4.76E-03	7.17E-04	Detected
	May 9 – May 25	2.36E-02	4.86E-03	9.05E-04	Detected
	May 25 – Jun. 16	3.08E-02	5.23E-03	4.87E-04	Detected
	Jun. 16 – Jul. 8	2.96E-02	5.59E-03	9.64E-04	Detected
	Jul. 8 – Jul. 20	3.03E-02	6.32E-03	8.31E-04	Detected
	Jul. 20 – Jul. 27	3.94E-02	9.40E-03	1.20E-03	Detected
	Jul. 27 - Aug. 23	2.18E-02	4.58E-03	5.16E-04	Detected
	Aug. 23 – Sep.	2.38E-02	4.94E-03	1.03E-03	Detected
	Sep. 30 – Oct. 24	2.52E-02	4.49E-03	5.58E-04	Detected
	Oct. 24 – Nov. 29	2.52E-02	4.31E-03	4.95E-04	Detected
	Nov. 29 – Dec.	2.03E-02	4.44E-03	8.81E-04	Detected
	Dec. 21 – Jan. 6	5.95E-02	1.23E-02	2.58E-03	Detected

*sampler was offline due to power outage

Table 3-23: Activity density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Near Field Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{234}U	Jan. 8 – Jan. 27	3.91E-02	8.90E-03	1.62E-03	Detected
	Jan. 27 – Feb. 10	3.45E-02	9.18E-03	2.02E-03	Detected
	Feb. 10 – Feb. 24	4.15E-02	1.05E-02	1.57E-03	Detected
	Feb. 24 – Mar. 9	3.07E-02	6.99E-03	1.03E-03	Detected
	Mar. 9 – Mar. 23	2.87E-02	6.12E-03	1.17E-03	Detected
	Mar. 23 – Apr. 6	3.23E-02	5.75E-03	5.82E-04	Detected
	Apr. 6 – Apr. 26	3.56E-02	6.23E-03	6.64E-04	Detected
	Apr. 26 – May 9	4.20E-02	7.27E-03	5.10E-04	Detected
	May 9 – May 25	3.91E-02	7.00E-03	4.51E-04	Detected
	May 25 – Jun. 16	3.07E-02	5.60E-03	3.43E-04	Detected
	Jun. 16 – Jul. 8	3.02E-02	5.66E-03	4.87E-04	Detected
	Jul. 8 – Jul. 20	3.66E-02	6.85E-03	4.33E-04	Detected

Table 3-23: Activity density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Near Field Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{234}U	Jul. 20 – Jul. 27	4.16E-02	1.24E-02	1.61E-03	Detected
	Jul. 27 - Aug. 23	2.83E-02	5.33E-03	4.38E-04	Detected
	Aug. 23 – Sep. 30	2.13E-02	4.41E-03	4.89E-04	Detected
	Sep. 30 – Oct. 24	2.08E-02	4.43E-03	6.02E-04	Detected
	Oct. 24 – Nov. 29	2.57E-02	4.39E-03	3.96E-04	Detected
	Nov. 29 – Dec. 21	3.49E-02	6.13E-03	6.16E-04	Detected
	Dec. 21 – Jan. 6	4.37E-02	1.01E-02	9.84E-04	Detected
^{235}U	Jan. 8 – Jan. 27	3.60E-03	1.51E-03	7.90E-04	Detected
	Jan. 27 – Feb. 10	4.49E-03	2.01E-03	1.75E-03	Detected
	Feb. 10 – Feb. 24	3.75E-03	1.90E-03	1.47E-03	Detected
	Feb. 24 – Mar. 9	1.48E-03	9.87E-04	8.16E-04	Detected
	Mar. 9 – Mar. 23	6.55E-04	8.25E-04	1.26E-03	Not detected
	Mar. 23 – Apr. 6	2.16E-03	7.98E-04	6.64E-04	Detected
	Apr. 6 – Apr. 26	2.03E-03	7.71E-04	6.43E-04	Detected
	Apr. 26 – May 9	2.10E-03	8.41E-04	3.29E-04	Detected
	May 9 – May 25	2.17E-03	8.69E-04	4.30E-04	Detected
	May 25 – Jun. 16	1.25E-03	6.12E-04	2.59E-04	Detected
	Jun. 16 – Jul. 8	2.04E-03	7.78E-04	5.36E-04	Detected
	Jul. 8 – Jul. 20	3.00E-03	1.01E-03	6.27E-04	Detected
	Jul. 20 – Jul. 27	8.56E-04	1.65E-03	1.76E-03	Not detected
	Jul. 27 - Aug. 23	1.28E-03	6.29E-04	4.80E-04	Detected
	Aug. 23 – Sep. 30	1.00E-03	5.84E-04	5.50E-04	Detected
	Sep. 30 – Oct. 24	5.01E-04	5.32E-04	6.25E-04	Not detected
	Oct. 24 – Nov. 29	8.08E-04	4.45E-04	3.36E-04	Detected
	Nov. 29 – Dec. 21	1.17E-03	6.79E-04	7.05E-04	Detected
	Dec. 21 – Jan. 6	2.48E-03	1.35E-03	7.07E-04	Detected
^{238}U	Jan. 8 – Jan. 27	3.73E-02	8.73E-03	1.68E-03	Detected
	Jan. 27 – Feb. 10	3.34E-02	9.04E-03	2.01E-03	Detected
	Feb. 10 – Feb. 24	4.36E-02	1.08E-02	1.86E-03	Detected
	Feb. 24 – Mar. 9	2.70E-02	6.56E-03	9.55E-04	Detected
	Mar. 9 – Mar. 23	2.74E-02	6.02E-03	1.79E-03	Detected
	Mar. 23 – Apr. 6	3.28E-02	5.80E-03	6.19E-04	Detected
	Apr. 6 – Apr. 26	3.60E-02	6.26E-03	8.75E-04	Detected
	Apr. 26 – May 9	3.92E-02	6.98E-03	8.09E-04	Detected
	May 9 – May 25	3.82E-02	6.92E-03	8.78E-04	Detected
	May 25 – Jun. 16	2.95E-02	5.46E-03	6.37E-04	Detected

Table 3-23: Activity density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Near Field Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{238}U	Jun. 16 – Jul. 8	2.93E-02	5.55E-03	7.82E-04	Detected
	Jul. 8 – Jul. 20	3.22E-02	6.37E-03	8.06E-04	Detected
	Jul. 20 – Jul. 27	4.03E-02	1.23E-02	1.76E-03	Detected
	Jul. 27 - Aug. 23	2.72E-02	5.22E-03	4.80E-04	Detected
	Aug. 23 – Sep. 30	1.79E-02	4.03E-03	6.57E-04	Detected
	Sep. 30 – Oct. 24	1.94E-02	4.25E-03	5.06E-04	Detected
	Oct. 24 – Nov. 29	2.26E-02	4.06E-03	5.32E-04	Detected
	Nov. 29 – Dec. 21	3.04E-02	5.64E-03	1.02E-03	Detected
	Dec. 21 – Jan. 6	4.18E-02	9.93E-03	1.38E-03	Detected

Table 3-24: Activity density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Cactus Flats Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{234}U	Jan. 8 – Jan. 27	3.78E-02	8.18E-03	1.03E-03	Detected
	Jan. 27 – Feb. 10	3.58E-02	7.79E-03	1.22E-03	Detected
	Feb. 10 – Feb. 24	3.14E-02	6.96E-03	1.07E-03	Detected
	Feb. 24 – Mar. 9	2.97E-02	6.79E-03	1.03E-03	Detected
	Mar. 9 – Mar. 23	3.82E-02	7.96E-03	1.34E-03	Detected
	Mar. 23 – Apr. 6	2.76E-02	5.68E-03	7.21E-04	Detected
	Apr. 6 – Apr. 26	4.05E-02	7.47E-03	8.07E-04	Detected
	Apr. 26 – May 9	4.94E-02	8.02E-03	5.60E-04	Detected
	May 9 – May 25	3.49E-02	6.40E-03	5.91E-04	Detected
	May 25 – Jun. 16	3.54E-02	6.12E-03	4.99E-04	Detected
	Jun. 16 – Jul. 8	3.61E-02	6.91E-03	9.09E-04	Detected
	Jul. 8 – Jul. 20	4.14E-02	8.56E-03	7.53E-04	Detected
	Jul. 20 – Jul. 27*	8.01E-02	3.30E-02	5.90E-03	Detected
	Jul. 27 - Aug. 23	3.13E-02	5.21E-03	4.07E-04	Detected
	Aug. 23 – Sep. 30	2.57E-02	3.55E-03	8.01E-04	Detected
	Sep. 30 – Oct. 24	2.48E-02	4.69E-03	4.58E-04	Detected
	Oct. 24 – Nov. 29	3.77E-02	6.77E-03	1.02E-03	Detected
	Nov. 29 – Dec. 21	3.46E-02	6.07E-03	7.66E-04	Detected
	Dec. 21 – Jan. 6	3.60E-02	8.74E-03	1.08E-03	Detected
^{235}U	Jan. 8 – Jan. 27	2.47E-03	1.22E-03	8.79E-04	Detected
	Jan. 27 – Feb. 10	1.63E-03	1.07E-03	9.02E-04	Detected
	Feb. 10 – Feb. 24	1.42E-03	9.73E-04	8.44E-04	Detected

Table 3-24: Activity density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Cactus Flats Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{235}U	Feb. 24 – Mar. 9	1.80E-03	1.03E-03	8.10E-04	Detected
	Mar. 9 – Mar. 23	1.90E-03	1.13E-03	1.09E-03	Detected
	Mar. 23 – Apr. 6	3.67E-03	1.15E-03	8.09E-04	Detected
	Apr. 6 – Apr. 26	1.31E-03	7.81E-04	4.60E-04	Detected
	Apr. 26 – May 9	2.85E-03	9.40E-04	3.21E-04	Detected
	May 9 – May 25	1.74E-03	7.67E-04	6.14E-04	Detected
	May 25 – Jun. 16	3.57E-03	9.43E-04	2.60E-04	Detected
	Jun. 16 – Jul. 8	1.47E-03	7.92E-04	4.43E-04	Detected
	Jul. 8 – Jul. 20	3.61E-03	1.33E-03	6.11E-04	Detected
	Jul. 20 – Jul. 27*	3.58E-03	5.01E-03	3.59E-03	Not detected
	Jul. 27 - Aug. 23	1.43E-03	5.49E-04	2.49E-04	Detected
	Aug. 23 – Sep. 30	4.08E-04	5.90E-04	8.07E-04	Not detected
	Sep. 30 – Oct. 24	1.07E-03	5.78E-04	5.64E-04	Detected
	Oct. 24 – Nov. 29	1.46E-03	8.24E-04	6.23E-04	Detected
	Nov. 29 – Dec. 21	1.65E-03	7.17E-04	5.45E-04	Detected
	Dec. 21 – Jan. 6	1.12E-03	1.06E-03	8.46E-04	Detected
^{238}U	Jan. 8 – Jan. 27	3.41E-02	7.81E-03	1.61E-03	Detected
	Jan. 27 – Feb. 10	3.22E-02	7.38E-03	1.05E-03	Detected
	Feb. 10 – Feb. 24	2.99E-02	6.79E-03	9.90E-04	Detected
	Feb. 24 – Mar. 9	2.90E-02	6.74E-03	1.22E-03	Detected
	Mar. 9 – Mar. 23	3.44E-02	7.56E-03	2.01E-03	Detected
	Mar. 23 – Apr. 6	3.16E-02	6.13E-03	6.53E-04	Detected
	Apr. 6 – Apr. 26	3.91E-02	7.33E-03	1.02E-03	Detected
	Apr. 26 – May 9	4.36E-02	7.40E-03	6.60E-04	Detected
	May 9 – May 25	3.07E-02	5.91E-03	7.97E-04	Detected
	May 25 – Jun. 16	3.33E-02	5.89E-03	4.97E-04	Detected
	Jun. 16 – Jul. 8	3.61E-02	6.89E-03	9.81E-04	Detected
	Jul. 8 – Jul. 20	4.08E-02	8.50E-03	1.07E-03	Detected
	Jul. 20 – Jul. 27*	8.98E-02	3.42E-02	5.44E-03	Detected
	Jul. 27 - Aug. 23	2.91E-02	4.96E-03	3.76E-04	Detected
	Aug. 23 – Sep. 30	2.06E-02	4.60E-03	7.04E-04	Detected
	Sep. 30 – Oct. 24	2.44E-02	4.66E-03	4.16E-04	Detected
	Oct. 24 – Nov. 29	3.33E-02	8.24E-04	6.23E-04	Detected
	Nov. 29 – Dec. 21	2.94E-02	7.17E-04	5.45E-04	Detected
	Dec. 21 – Jan. 6	3.60E-02	1.06E-03	8.46E-04	Detected

* low flow rate and mass loading; use values with caution

Table 3-25: Activity concentrations of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Onsite Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{137}Cs	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	2.31E-06	1.31E-06	4.30E-06	Not detected
	Feb. 24 – Mar. 9	1.38E-06	9.76E-07	3.21E-06	Not detected
	Mar. 9 – Mar. 23	8.80E-07	9.80E-07	3.24E-06	Not detected
	Mar. 23 – Apr. 6	4.44E-08	9.16E-07	3.04E-06	Not detected
	Apr. 6 – Apr. 26	-4.67E-07	5.98E-07	1.99E-06	Not detected
	Apr. 26 – May 9	1.06E-07	9.57E-07	3.17E-06	Not detected
	May 9 – May 25	-2.93E-08	1.17E-06	3.89E-06	Not detected
	May 25 – Jun. 16	-1.89E-06	1.36E-06	4.53E-06	Not detected
	Jun. 16 – Jul. 8	-9.92E-09	6.97E-07	2.31E-06	Not detected
	Jul. 8 – Jul. 20	2.79E-06	1.25E-06	4.10E-06	Not detected
	Jul. 20 – Jul. 27	-6.90E-08	1.72E-06	5.70E-06	Not detected
	Jul. 27 - Aug. 23	6.53E-07	4.83E-07	1.59E-06	Not detected
	Aug. 23 – Sep. 30	4.17E-07	3.13E-07	1.03E-06	Not detected
	Sep. 30 – Oct. 24	6.43E-07	4.94E-07	1.63E-06	Not detected
	Oct. 24 – Nov. 29	2.42E-07	3.29E-07	1.09E-06	Not detected
	Nov. 29 – Dec. 21	5.62E-07	6.75E-07	2.23E-06	Not detected
	Dec. 21 – Jan. 6	1.06E-06	7.20E-07	2.37E-06	Not detected
^{60}Co	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	-1.91E-06	1.35E-06	4.53E-06	Not detected
	Feb. 24 – Mar. 9	2.26E-07	9.94E-07	3.30E-06	Not detected
	Mar. 9 – Mar. 23	-9.14E-07	1.00E-06	3.35E-06	Not detected
	Mar. 23 – Apr. 6	1.92E-07	8.97E-07	2.98E-06	Not detected
	Apr. 6 – Apr. 26	5.33E-07	5.88E-07	1.95E-06	Not detected
	Apr. 26 – May 9	-1.13E-06	9.69E-07	3.25E-06	Not detected
	May 9 – May 25	1.14E-08	9.66E-07	3.24E-06	Not detected
	May 25 – Jun. 16	-1.27E-06	1.30E-06	4.38E-06	Not detected
	Jun. 16 – Jul. 8	-6.63E-07	5.86E-07	1.97E-06	Not detected
	Jul. 8 – Jul. 20	-8.97E-07	1.06E-06	3.53E-06	Not detected
	Jul. 20 – Jul. 27	-6.56E-07	1.73E-06	5.78E-06	Not detected
	Jul. 27 - Aug. 23	3.39E-07	4.94E-07	1.64E-06	Not detected
	Aug. 23 – Sep. 30	4.78E-07	3.29E-07	1.11E-06	Not detected
	Sep. 30 – Oct. 24	6.49E-08	5.16E-07	1.72E-06	Not detected
	Oct. 24 – Nov. 29	1.20E-07	3.39E-07	1.13E-06	Not detected
	Nov. 29 – Dec. 21	2.95E-07	6.60E-07	1.89E-06	Not detected
	Dec. 21 – Jan. 6	2.68E-07	7.60E-07	2.54E-06	Not detected

Table 3-25: Activity concentrations of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Onsite Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{40}K	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	5.36E-05	1.63E-05	5.29E-05	Detected
	Feb. 24 – Mar. 9	2.19E-05	1.24E-05	4.08E-05	Not detected
	Mar. 9 – Mar. 23	4.12E-05	1.23E-05	3.99E-05	Detected
	Mar. 23 – Apr. 6	7.58E-05	1.14E-05	3.60E-05	Detected
	Apr. 6 – Apr. 26	2.63E-05	7.67E-06	2.63E-05	Not detected
	Apr. 26 – May 9	6.28E-05	1.19E-05	3.80E-05	Detected
	May 9 – May 25	4.77E-05	1.19E-05	3.70E-05	Detected
	May 25 – Jun. 16	4.99E-05	1.30E-05	4.15E-05	Detected
	Jun. 16 – Jul. 8	3.50E-05	7.20E-06	2.23E-05	Detected
	Jul. 8 – Jul. 20	5.61E-05	1.30E-05	4.07E-05	Detected
	Jul. 20 – Jul. 27	6.95E-05	2.17E-05	7.07E-05	Not detected
	Jul. 27 - Aug. 23	2.72E-05	5.95E-06	1.91E-05	Detected
	Aug. 23 – Sep. 30	1.80E-05	4.00E-06	1.29E-05	Detected
	Sep. 30 – Oct. 24	3.28E-05	6.25E-06	2.00E-05	Detected
	Oct. 24 – Nov. 29	1.77E-05	4.23E-06	1.37E-05	Detected
	Nov. 29 – Dec. 21	3.81E-05	7.12E-06	2.18E-05	Detected
	Dec. 21 – Jan. 6	3.77E-05	9.10E-06	2.93E-05	Detected

*sampler was offline due to power outage

Table 3-26: Activity concentrations of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Near Field Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{137}Cs	Jan. 8 – Jan. 27	-4.75E-07	8.01E-07	2.66E-06	Not detected
	Jan. 27 – Feb. 10	-6.93E-07	8.75E-07	2.91E-06	Not detected
	Feb. 10 – Feb. 24	1.59E-06	1.10E-06	3.60E-06	Not detected
	Feb. 24 – Mar. 9	1.20E-06	1.11E-06	3.67E-06	Not detected
	Mar. 9 – Mar. 23	1.25E-06	1.15E-06	3.79E-06	Not detected
	Mar. 23 – Apr. 6	-5.27E-07	1.18E-06	3.91E-06	Not detected
	Apr. 6 – Apr. 26	8.19E-07	7.76E-07	2.56E-06	Not detected
	Apr. 26 – May 9	9.86E-07	1.23E-06	4.05E-06	Not detected
	May 9 – May 25	1.32E-06	1.69E-06	5.57E-06	Not detected
	May 25 – Jun. 16	7.22E-07	6.11E-07	2.02E-06	Not detected
	Jun. 16 – Jul. 8	1.46E-07	1.33E-06	4.40E-06	Not detected
	Jul. 8 – Jul. 20	1.02E-06	3.65E-06	1.21E-05	Not detected
	Jul. 20 – Jul. 27	1.10E-06	2.13E-06	7.03E-06	Not detected

Table 3-26: Activity concentrations of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Near Field Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{137}Cs	Jul. 27 - Aug. 23	-1.55E-08	5.90E-07	1.96E-06	Not detected
	Aug. 23 – Sep. 30	2.66E-07	3.97E-07	1.31E-06	Not detected
	Sep. 30 – Oct. 24	7.69E-07	6.12E-07	2.01E-06	Not detected
	Oct. 24 – Nov. 29	5.69E-07	4.32E-07	1.44E-06	Not detected
	Nov. 29 – Dec. 21	8.70E-07	1.29E-06	4.27E-06	Not detected
	Dec. 21 – Jan. 6	1.42E-07	9.30E-07	3.08E-06	Not detected
^{60}Co	Jan. 8 – Jan. 27	1.57E-07	6.52E-07	2.17E-06	Not detected
	Jan. 27 – Feb. 10	-6.22E-07	8.83E-07	2.95E-06	Not detected
	Feb. 10 – Feb. 24	1.12E-06	8.95E-07	2.95E-06	Not detected
	Feb. 24 – Mar. 9	-1.77E-01	0.00E+00	3.25E-06	Not detected
	Mar. 9 – Mar. 23	-2.45E-07	9.50E-07	3.17E-06	Not detected
	Mar. 23 – Apr. 6	-5.45E-07	9.66E-07	3.23E-06	Not detected
	Apr. 6 – Apr. 26	-8.85E-08	6.39E-07	2.13E-06	Not detected
	Apr. 26 – May 9	-7.04E-07	1.02E-06	3.41E-06	Not detected
	May 9 – May 25	-1.14E-06	1.63E-06	5.46E-06	Not detected
	May 25 – Jun. 16	-4.36E-07	6.36E-07	2.13E-06	Not detected
	Jun. 16 – Jul. 8	2.53E-07	1.24E-06	4.14E-06	Not detected
	Jul. 8 – Jul. 20	-9.44E-06	1.21E-05	4.06E-05	Not detected
	Jul. 20 – Jul. 27	-2.12E-06	1.82E-06	6.10E-06	Not detected
	Jul. 27 - Aug. 23	-4.18E-07	4.84E-07	1.62E-06	Not detected
	Aug. 23 – Sep. 30	2.08E-08	3.29E-07	1.09E-06	Not detected
	Sep. 30 – Oct. 24	1.91E-07	5.12E-07	1.70E-06	Not detected
	Oct. 24 – Nov. 29	4.97E-08	3.59E-06	1.20E-06	Not detected
	Nov. 29 – Dec. 21	1.07E-06	1.23E-06	4.08E-06	Not detected
	Dec. 21 – Jan. 6	7.55E-07	7.80E-07	2.61E-06	Not detected
^{40}K	Jan. 8 – Jan. 27	2.90E-05	8.09E-06	2.58E-05	Detected
	Jan. 27 – Feb. 10	2.49E-05	1.06E-05	3.48E-05	Not detected
	Feb. 10 – Feb. 24	5.17E-05	1.17E-05	3.65E-05	Detected
	Feb. 24 – Mar. 9	3.05E-05	1.16E-05	3.74E-05	Not detected
	Mar. 9 – Mar. 23	4.49E-05	2.12E-05	6.95E-05	Not detected
	Mar. 23 – Apr. 6	5.97E-05	1.26E-05	3.90E-05	Detected
	Apr. 6 – Apr. 26	8.71E-06	8.30E-06	2.56E-05	Not detected
	Apr. 26 – May 9	6.65E-05	1.28E-05	3.94E-05	Detected
	May 9 – May 25	1.91E-05	1.69E-05	5.59E-05	Not detected
	May 25 – Jun. 16	3.18E-05	7.85E-06	2.54E-05	Detected
	Jun. 16 – Jul. 8	2.70E-05	1.30E-05	4.27E-05	Not detected

Table 3-26: Activity concentrations of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Near Field Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{40}K	Jul. 8 – Jul. 20	6.97E-05	2.28E-05	7.38E-05	Not detected
	Jul. 20 – Jul. 27	6.72E-05	2.18E-05	7.02E-05	Not detected
	Jul. 27 - Aug. 23	2.55E-05	6.05E-06	1.62E-06	Detected
	Aug. 23 – Sep. 30	1.08E-05	4.13E-06	1.33E-05	Not detected
	Sep. 30 – Oct. 24	3.47E-05	6.56E-06	2.01E-05	Detected
	Oct. 24 – Nov. 29	1.79E-05	4.68E-06	1.48E-05	Detected
	Nov. 29 – Dec. 21	3.33E-05	1.32E-05	4.29E-05	Not detected
	Dec. 21 – Jan. 6	2.24E-05	9.72E-06	3.16E-05	Not detected

Table 3-27: Activity concentrations of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Cactus Flats Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{137}Cs	Jan. 8 – Jan. 27	2.04E-06	1.47E-06	4.84E-06	Not detected
	Jan. 27 – Feb. 10	9.28E-07	1.06E-06	3.50E-06	Not detected
	Feb. 10 – Feb. 24	-8.59E-07	2.02E-06	6.70E-06	Not detected
	Feb. 24 – Mar. 9	1.27E-06	1.99E-06	6.58E-06	Not detected
	Mar. 9 – Mar. 23	-1.41E-06	2.04E-06	6.81E-06	Not detected
	Mar. 23 – Apr. 6	-4.28E-07	2.05E-06	6.83E-06	Not detected
	Apr. 6 – Apr. 26	1.46E-06	1.39E-06	4.59E-06	Not detected
	Apr. 26 – May 9	1.74E-06	2.17E-06	7.16E-06	Not detected
	May 9 – May 25	2.71E-07	7.33E-07	2.43E-06	Not detected
	May 25 – Jun. 16	9.78E-07	5.54E-07	1.82E-06	Not detected
	Jun. 16 – Jul. 8	-1.51E-07	6.13E-07	2.04E-06	Not detected
	Jul. 8 – Jul. 20	7.88E-07	1.19E-06	3.93E-06	Not detected
	Jul. 20 – Jul. 27*	6.29E-06	1.21E-05	3.99E-05	Not detected
	Jul. 27 - Aug. 23	-1.32E-06	1.12E-06	3.74E-06	Not detected
	Aug. 23 – Sep. 30	1.16E-07	7.50E-07	2.49E-06	Not detected
	Sep. 30 – Oct. 24	3.93E-07	1.17E-06	3.89E-06	Not detected
	Oct. 24 – Nov. 29	4.73E-07	6.81E-07	2.25E-06	Not detected
	Nov. 29 – Dec. 21	5.28E-07	5.47E-07	1.80E-06	Not detected
	Dec. 21 – Jan. 6	3.33E-06	1.83E-06	6.11E-06	Not detected
^{60}Co	Jan. 8 – Jan. 27	-7.61E-07	1.43E-06	4.79E-06	Not detected
	Jan. 27 – Feb. 10	-9.14E-07	8.87E-07	2.97E-06	Not detected
	Feb. 10 – Feb. 24	-1.45E-07	1.92E-06	6.40E-06	Not detected
	Feb. 24 – Mar. 9	-3.52E-06	2.01E-06	6.79E-06	Not detected

Table 3-27: Activity concentrations of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Cactus Flats Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{60}Co	Mar. 9 – Mar. 23	-1.16E-06	1.93E-06	6.46E-06	Not detected
	Mar. 23 – Apr. 6	2.37E-08	1.90E-06	6.35E-06	Not detected
	Apr. 6 – Apr. 26	-1.14E-06	1.36E-06	4.58E-07	Not detected
	Apr. 26 – May 9	-2.70E-06	2.09E-06	7.05E-06	Not detected
	May 9 – May 25	-1.01E-06	7.50E-07	2.52E-06	Not detected
	May 25 – Jun. 16	-1.52E-07	5.76E-07	1.92E-06	Not detected
	Jun. 16 – Jul. 8	-2.81E-07	6.22E-07	2.08E-06	Not detected
	Jul. 8 – Jul. 20	-1.57E-06	1.24E-05	4.15E-06	Not detected
	Jul. 20 – Jul. 27*	-1.65E-05	1.20E-05	4.05E-05	Not detected
	Jul. 27 - Aug. 23	-4.41E-07	1.04E-06	3.48E-06	Not detected
	Aug. 23 – Sep. 30	7.13E-07	6.99E-07	2.31E-06	Not detected
	Sep. 30 – Oct. 24	4.45E-07	1.15E-06	3.85E-06	Not detected
	Oct. 24 – Nov. 29	8.08E-07	7.25E-07	2.43E-06	Not detected
	Nov. 29 – Dec. 21	9.42E-07	5.69E-07	1.89E-06	Not detected
	Dec. 21 – Jan. 6	1.61E-06	1.73E-06	5.80E-06	Not detected
^{40}K	Jan. 8 – Jan. 27	2.28E-05	1.46E-05	4.79E-05	Not detected
	Jan. 27 – Feb. 10	3.50E-05	1.09E-05	3.48E-05	Detected
	Feb. 10 – Feb. 24	3.48E-05	1.94E-05	6.37E-05	Not detected
	Feb. 24 – Mar. 9	2.35E-05	1.96E-05	6.48E-05	Not detected
	Mar. 9 – Mar. 23	6.52E-05	1.14E-05	3.44E-05	Detected
	Mar. 23 – Apr. 6	5.19E-05	1.98E-05	6.42E-05	Not detected
	Apr. 6 – Apr. 26	5.26E-05	1.35E-05	4.29E-05	Detected
	Apr. 26 – May 9	6.53E-05	2.12E-05	6.85E-05	Not detected
	May 9 – May 25	2.90E-05	9.61E-06	3.13E-05	Not detected
	May 25 – Jun. 16	4.17E-05	6.95E-06	2.21E-05	Detected
	Jun. 16 – Jul. 8	3.41E-05	7.52E-06	2.08E-06	Detected
	Jul. 8 – Jul. 20	5.00E-05	1.50E-05	4.88E-05	Detected
	Jul. 20 – Jul. 27*	8.23E-05	1.18E-04	3.90E-04	Not detected
	Jul. 27 - Aug. 23	2.07E-05	1.08E-05	3.53E-05	Not detected
	Aug. 23 – Sep. 30	1.83E-05	7.12E-06	2.31E-05	Not detected
	Sep. 30 – Oct. 24	3.38E-05	1.14E-05	3.70E-05	Not detected
	Oct. 24 – Nov. 29	2.95E-05	8.31E-06	2.69E-05	Detected
	Nov. 29 – Dec. 21	3.04E-05	6.89E-06	2.22E-05	Detected
	Dec. 21 – Jan. 6	3.37E-05	1.70E-05	5.55E-05	Not detected

*low flow rate and mass loading; use values with caution

Table 3-28: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Onsite Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{137}Cs	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	6.97E-02	3.95E-02	1.30E-01	Not detected
	Feb. 24 – Mar. 9	4.21E-02	2.97E-02	9.77E-02	Not detected
	Mar. 9 – Mar. 23	1.74E-02	1.93E-02	6.38E-02	Not detected
	Mar. 23 – Apr. 6	6.84E-04	1.41E-02	4.68E-02	Not detected
	Apr. 6 – Apr. 26	-1.40E-02	1.79E-02	5.95E-02	Not detected
	Apr. 26 – May 9	1.73E-03	1.56E-02	5.19E-02	Not detected
	May 9 – May 25	-7.16E-04	2.86E-02	9.53E-02	Not detected
	May 25 – Jun. 16	-5.20E-02	3.73E-02	1.24E-01	Not detected
	Jun. 16 – Jul. 8	-3.18E-04	2.23E-02	7.40E-02	Not detected
	Jul. 8 – Jul. 20	6.23E-02	2.79E-02	9.15E-02	Not detected
	Jul. 20 – Jul. 27	-1.51E-03	3.77E-02	1.25E-01	Not detected
	Jul. 27 - Aug. 23	2.17E-02	1.60E-02	5.29E-02	Not detected
	Aug. 23 – Sep. 30	2.02E-02	1.52E-02	5.00E-02	Not detected
	Sep. 30 – Oct. 24	1.69E-02	1.30E-02	4.29E-02	Not detected
	Oct. 24 – Nov. 29	8.20E-03	1.12E-02	3.69E-02	Not detected
	Nov. 29 – Dec. 21	1.58E-02	1.90E-02	6.28E-02	Not detected
	Dec. 21 – Jan. 6	5.51E-02	3.74E-02	1.23E-01	Not detected
^{60}Co	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	-5.75E-02	4.06E-02	1.37E-01	Not detected
	Feb. 24 – Mar. 9	6.86E-03	3.02E-02	1.00E-01	Not detected
	Mar. 9 – Mar. 23	-1.80E-02	1.97E-02	6.61E-02	Not detected
	Mar. 23 – Apr. 6	2.95E-03	1.38E-02	4.60E-02	Not detected
	Apr. 6 – Apr. 26	1.59E-02	1.76E-02	5.82E-02	Not detected
	Apr. 26 – May 9	-1.85E-02	1.58E-02	5.32E-02	Not detected
	May 9 – May 25	2.78E-04	2.36E-02	7.93E-02	Not detected
	May 25 – Jun. 16	-3.48E-02	3.59E-02	1.20E-01	Not detected
	Jun. 16 – Jul. 8	-2.12E-02	1.88E-02	6.30E-02	Not detected
	Jul. 8 – Jul. 20	-2.00E-02	2.36E-02	7.88E-02	Not detected
	Jul. 20 – Jul. 27	-1.44E-02	3.80E-02	1.27E-01	Not detected
	Jul. 27 - Aug. 23	1.13E-02	1.64E-02	5.44E-02	Not detected
	Aug. 23 – Sep. 30	2.32E-02	1.60E-02	5.38E-02	Not detected
	Sep. 30 – Oct. 24	1.71E-03	1.36E-02	4.52E-02	Not detected
	Oct. 24 – Nov. 29	4.06E-03	1.15E-02	3.84E-02	Not detected
	Nov. 29 – Dec. 21	8.31E-03	1.86E-02	5.33E-02	Not detected
	Dec. 21 – Jan. 6	1.39E-02	3.94E-02	1.32E-01	Not detected

Table 3-28: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Onsite Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{40}K	Jan. 8 – Jan. 27*	-	-	-	-
	Jan. 27 – Feb. 10*	-	-	-	-
	Feb. 10 – Feb. 24	1.62E+00	4.92E-01	1.59E+00	Detected
	Feb. 24 – Mar. 9	6.67E-01	3.77E-01	1.24E+00	Not detected
	Mar. 9 – Mar. 23	8.13E-01	2.42E-01	7.87E-01	Detected
	Mar. 23 – Apr. 6	1.17E+00	1.76E-01	5.56E-01	Detected
	Apr. 6 – Apr. 26	7.85E-01	2.29E-01	7.87E-01	Not detected
	Apr. 26 – May 9	1.03E+00	1.95E-01	6.21E-01	Detected
	May 9 – May 25	1.17E+00	2.91E-01	9.05E-01	Detected
	May 25 – Jun. 16	1.37E+00	3.58E-01	1.14E+00	Detected
	Jun. 16 – Jul. 8	1.12E+00	2.30E-01	7.14E-01	Detected
	Jul. 8 – Jul. 20	1.25E+00	2.90E-01	9.09E-01	Detected
	Jul. 20 – Jul. 27	1.53E+00	4.76E-01	1.55E+00	Not detected
	Jul. 27 - Aug. 23	9.03E-01	1.98E-01	6.34E-01	Detected
	Aug. 23 – Sep. 30	8.73E-01	1.94E-01	6.24E-01	Detected
	Sep. 30 – Oct. 24	8.63E-01	1.64E-01	5.26E-01	Detected
	Oct. 24 – Nov. 29	6.00E-01	1.44E-01	4.63E-01	Detected
	Nov. 29 – Dec. 21	1.07E+00	2.01E-01	6.14E-01	Detected
	Dec. 21 – Jan. 6	1.95E+00	4.72E-01	1.52E+00	Detected

*sampler was offline due to power outage

Table 3-29: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Near Field Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{137}Cs	Jan. 8 – Jan. 27	-2.54E-02	4.29E-02	1.43E-01	Not detected
	Jan. 27 – Feb. 10	-2.61E-02	3.29E-02	1.10E-01	Not detected
	Feb. 10 – Feb. 24	5.02E-02	3.45E-02	1.13E-01	Not detected
	Feb. 24 – Mar. 9	3.44E-02	3.19E-02	1.05E-01	Not detected
	Mar. 9 – Mar. 23	2.76E-02	2.54E-02	8.38E-02	Not detected
	Mar. 23 – Apr. 6	-9.39E-03	2.10E-02	6.97E-02	Not detected
	Apr. 6 – Apr. 26	2.29E-02	2.17E-02	7.15E-02	Not detected
	Apr. 26 – May 9	2.05E-02	2.55E-02	8.41E-02	Not detected
	May 9 – May 25	3.74E-02	4.78E-02	1.58E-01	Not detected
	May 25 – Jun. 16	2.00E-02	1.70E-02	5.60E-02	Not detected
	Jun. 16 – Jul. 8	4.75E-03	4.31E-02	1.43E-01	Not detected
	Jul. 8 – Jul. 20	2.28E-02	8.13E-02	2.69E-01	Not detected
	Jul. 20 – Jul. 27	3.97E-02	7.69E-02	2.54E-01	Not detected

Table 3-29: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Near Field Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{137}Cs	Jul. 27 - Aug. 23	-5.89E-04	2.24E-02	7.44E-02	Not detected
	Aug. 23 – Sep. 30	1.35E-02	2.02E-02	6.67E-02	Not detected
	Sep. 30 – Oct. 24	2.35E-02	1.87E-02	6.17E-02	Not detected
	Oct. 24 – Nov. 29	2.21E-02	1.68E-02	5.59E-02	Not detected
	Nov. 29 – Dec. 21	2.66E-02	3.95E-02	1.31E-01	Not detected
	Dec. 21 – Jan. 6	8.33E-03	5.47E-02	1.81E-01	Not detected
^{60}Co	Jan. 8 – Jan. 27	8.40E-03	3.49E-02	1.16E-01	Not detected
	Jan. 27 – Feb. 10	-2.34E-02	3.32E-02	1.11E-01	Not detected
	Feb. 10 – Feb. 24	3.52E-02	2.82E-02	9.29E-02	Not detected
	Feb. 24 – Mar. 9	-5.06E+03	0.00E+00	9.32E-02	Not detected
	Mar. 9 – Mar. 23	-5.41E-03	2.10E-02	7.01E-02	Not detected
	Mar. 23 – Apr. 6	-9.72E-03	1.72E-02	5.75E-02	Not detected
	Apr. 6 – Apr. 26	-2.47E-03	1.79E-02	5.96E-02	Not detected
	Apr. 26 – May 9	-1.46E-02	2.12E-02	7.08E-02	Not detected
	May 9 – May 25	-3.23E-02	4.61E-02	1.55E-01	Not detected
	May 25 – Jun. 16	-1.21E-02	1.77E-02	5.91E-02	Not detected
	Jun. 16 – Jul. 8	8.21E-03	4.03E-02	1.34E-01	Not detected
	Jul. 8 – Jul. 20	-2.10E-01	2.69E-01	9.04E-01	Not detected
	Jul. 20 – Jul. 27	-7.67E-02	6.58E-02	2.21E-01	Not detected
	Jul. 27 - Aug. 23	-1.59E-02	1.84E-02	6.16E-02	Not detected
	Aug. 23 – Sep. 30	1.06E-03	1.67E-02	5.56E-02	Not detected
	Sep. 30 – Oct. 24	5.86E-03	1.57E-02	5.20E-02	Not detected
	Oct. 24 – Nov. 29	1.93E-03	1.40E-01	4.65E-02	Not detected
	Nov. 29 – Dec. 21	3.26E-02	3.77E-02	1.25E-01	Not detected
	Dec. 21 – Jan. 6	4.44E-02	4.59E-02	1.54E-01	Not detected
^{40}K	Jan. 8 – Jan. 27	1.55E+00	4.33E-01	1.38E+00	Detected
	Jan. 27 – Feb. 10	9.38E-01	4.00E-01	1.31E+00	Not detected
	Feb. 10 – Feb. 24	1.63E+00	3.67E-01	1.15E+00	Detected
	Feb. 24 – Mar. 9	8.73E-01	3.32E-01	1.07E+00	Not detected
	Mar. 9 – Mar. 23	9.94E-01	4.69E-01	1.54E+00	Not detected
	Mar. 23 – Apr. 6	1.07E+00	2.24E-01	6.96E-01	Detected
	Apr. 6 – Apr. 26	2.44E-01	2.32E-01	7.17E-01	Not detected
	Apr. 26 – May 9	1.38E+00	2.67E-01	8.19E-01	Detected
	May 9 – May 25	5.41E-01	4.80E-01	1.58E+00	Not detected
	May 25 – Jun. 16	8.84E-01	2.18E-01	7.05E-01	Detected
	Jun. 16 – Jul. 8	8.78E-01	4.24E-01	1.39E+00	Not detected

Table 3-29: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Near Field Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{40}K	Jul. 8 – Jul. 20	1.55E+00	5.08E-01	1.64E+00	Not detected
	Jul. 20 – Jul. 27	2.43E+00	7.90E-01	2.54E+00	Not detected
	Jul. 27 - Aug. 23	9.72E-01	2.30E-01	6.17E-02	Detected
	Aug. 23 – Sep. 30	5.50E-01	2.10E-01	6.78E-01	Not detected
	Sep. 30 – Oct. 24	1.06E+00	2.01E-01	6.17E-01	Detected
	Oct. 24 – Nov. 29	6.95E-01	1.82E-01	5.76E-01	Detected
	Nov. 29 – Dec. 21	1.02E+00	4.02E-01	1.31E+00	Not detected
	Dec. 21 – Jan. 6	1.32E+00	5.71E-01	1.86E+00	Not detected

Table 3-30: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Cactus Flats Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{137}Cs	Jan. 8 – Jan. 27	9.58E-02	6.91E-02	2.27E-01	Not detected
	Jan. 27 – Feb. 10	2.86E-02	3.27E-02	1.08E-01	Not detected
	Feb. 10 – Feb. 24	-2.41E-02	5.66E-02	1.88E-01	Not detected
	Feb. 24 – Mar. 9	3.70E-02	5.81E-02	1.92E-01	Not detected
	Mar. 9 – Mar. 23	-4.06E-02	5.90E-02	1.96E-01	Not detected
	Mar. 23 – Apr. 6	-9.37E-03	4.50E-02	1.50E-01	Not detected
	Apr. 6 – Apr. 26	5.65E-02	5.39E-02	1.78E-01	Not detected
	Apr. 26 – May 9	3.81E-02	4.75E-02	1.57E-01	Not detected
	May 9 – May 25	7.47E-03	2.02E-02	6.70E-02	Not detected
	May 25 – Jun. 16	2.94E-02	1.67E-02	5.48E-02	Not detected
	Jun. 16 – Jul. 8	-5.52E-03	2.25E-02	7.47E-02	Not detected
	Jul. 8 – Jul. 20	2.01E-02	3.04E-02	1.01E-01	Not detected
	Jul. 20 – Jul. 27*	2.30E-01	4.41E-01	1.46E+00	Not detected
	Jul. 27 - Aug. 23	-4.09E-02	3.48E-02	1.16E-01	Not detected
	Aug. 23 – Sep. 30	5.94E-03	3.85E-02	1.28E-01	Not detected
	Sep. 30 – Oct. 24	1.21E-02	3.60E-02	1.19E-01	Not detected
	Oct. 24 – Nov. 29	1.73E-02	2.50E-02	8.26E-02	Not detected
	Nov. 29 – Dec. 21	1.60E-02	1.65E-02	5.46E-02	Not detected
	Dec. 21 – Jan. 6	1.73E-01	9.49E-02	3.17E-01	Not detected
^{60}Co	Jan. 8 – Jan. 27	-3.58E-02	6.72E-02	2.25E-01	Not detected
	Jan. 27 – Feb. 10	-2.82E-02	2.74E-02	9.17E-02	Not detected
	Feb. 10 – Feb. 24	-4.08E-03	5.39E-02	1.80E-01	Not detected
	Feb. 24 – Mar. 9	-1.03E-01	5.87E-02	1.98E-01	Not detected

Table 3-30: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Cactus Flats Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{60}Co	Mar. 9 – Mar. 23	-3.34E-02	5.57E-02	1.87E-01	Not detected
	Mar. 23 – Apr. 6	5.20E-04	4.17E-02	1.39E-01	Not detected
	Apr. 6 – Apr. 26	-4.43E-02	5.29E-02	1.77E-02	Not detected
	Apr. 26 – May 9	-5.92E-02	4.59E-02	1.54E-01	Not detected
	May 9 – May 25	-2.78E-02	2.07E-02	6.96E-02	Not detected
	May 25 – Jun. 16	-4.56E-03	1.73E-02	5.78E-02	Not detected
	Jun. 16 – Jul. 8	-1.03E-02	2.28E-02	7.62E-02	Not detected
	Jul. 8 – Jul. 20	-4.02E-02	3.16E-01	1.06E-01	Not detected
	Jul. 20 – Jul. 27*	-6.02E-01	4.39E-01	1.48E+00	Not detected
	Jul. 27 - Aug. 23	-1.37E-02	3.23E-02	1.08E-01	Not detected
	Aug. 23 – Sep. 30	3.66E-02	3.59E-02	1.19E-01	Not detected
	Sep. 30 – Oct. 24	1.37E-02	3.54E-02	1.18E-01	Not detected
	Oct. 24 – Nov. 29	2.96E-02	2.66E-02	8.92E-02	Not detected
	Nov. 29 – Dec. 21	2.85E-02	1.72E-02	5.73E-02	Not detected
	Dec. 21 – Jan. 6	8.33E-02	8.96E-02	3.01E-01	Not detected
^{40}K	Jan. 8 – Jan. 27	1.07E+00	6.86E-01	2.25E+00	Not detected
	Jan. 27 – Feb. 10	1.08E+00	3.35E-01	1.07E+00	Not detected
	Feb. 10 – Feb. 24	9.78E-01	5.44E-01	1.79E+00	Not detected
	Feb. 24 – Mar. 9	6.88E-01	5.73E-01	1.89E+00	Not detected
	Mar. 9 – Mar. 23	1.88E+00	3.28E-01	9.94E-01	Not detected
	Mar. 23 – Apr. 6	1.14E+00	4.34E-01	1.41E+00	Not detected
	Apr. 6 – Apr. 26	2.04E+00	5.22E-01	1.66E+00	Detected
	Apr. 26 – May 9	1.43E+00	4.65E-01	1.50E+00	Not detected
	May 9 – May 25	8.00E-01	2.65E-01	8.64E-01	Not detected
	May 25 – Jun. 16	1.25E+00	2.09E-01	6.64E-01	Not detected
	Jun. 16 – Jul. 8	1.25E+00	2.76E-01	7.62E-02	Not detected
	Jul. 8 – Jul. 20	1.28E+00	3.84E-01	1.25E+00	Not detected
	Jul. 20 – Jul. 27*	3.01E+00	4.29E+00	1.42E+01	Not detected
	Jul. 27 - Aug. 23	6.42E-01	3.35E-01	1.10E+00	Not detected
	Aug. 23 – Sep. 30	9.37E-01	3.65E-01	1.19E+00	Not detected
	Sep. 30 – Oct. 24	1.04E+00	3.52E-01	1.14E+00	Not detected
	Oct. 24 – Nov. 29	1.08E+00	3.05E-01	9.87E-01	Detected
	Nov. 29 – Dec. 21	9.19E-01	2.08E-01	6.71E-01	Detected
	Dec. 21 – Jan. 6	1.75E+00	8.81E-01	2.88E+00	Not detected

*low flow rate and mass loading; use values with caution

Table 3-31: Activity concentrations of ^{241}Am, $^{239+240}Pu$ and ^{238}Pu in the filter samples collected from Loving Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{241}Am	Jan. 8 – Jan. 27	1.16E-08	6.85E-09	9.24E-09	Detected
	Jan. 27 – Feb. 10	1.86E-08	1.24E-08	2.20E-08	Not detected
	Feb. 10 – Feb. 24	1.89E-08	1.08E-08	1.73E-08	Detected
	Feb. 24 – Mar. 9	1.54E-08	8.60E-09	9.49E-09	Detected
	Mar. 9 – Mar. 23	1.72E-08	9.81E-09	1.42E-08	Detected
	Mar. 23 – Apr. 6	2.07E-08	1.01E-08	1.18E-08	Detected
	Apr. 6 – Apr. 26	1.72E-08	7.25E-09	6.14E-09	Detected
	Apr. 26 – May 9	5.11E-09	7.25E-09	1.53E-08	Not detected
	May 9 – May 25	8.00E-09	7.35E-09	1.41E-08	Not detected
	May 25 – Jun. 16	5.20E-10	4.54E-10	7.81E-10	Not detected
	Jun. 16 – Jul. 8	1.16E-08	6.10E-09	6.38E-09	Detected
	Jul. 8 – Jul. 20	2.59E-08	1.65E-08	2.86E-08	Not detected
	Jul. 20 – Jul. 27	1.97E-08	1.78E-08	3.41E-08	Not detected
	Jul. 27 - Aug. 23	9.73E-09	5.58E-09	8.05E-09	Detected
	Aug. 23 – Sep. 30	3.09E-09	3.01E-09	5.98E-09	Not detected
	Sep. 30 – Oct. 24	6.91E-09	6.60E-09	1.36E-08	Not detected
	Oct. 24 – Nov. 29	7.86E-09	4.52E-09	7.21E-09	Detected
	Nov. 29 – Dec. 21	5.14E-09	6.59E-09	1.44E-08	Not detected
	Dec. 21 – Jan. 6	1.76E-08	1.01E-08	1.65E-08	Detected
$^{239+240}Pu$	Jan. 8 – Jan. 27	-3.57E-11	2.76E-10	7.61E-10	Not detected
	Jan. 27 – Feb. 10	5.47E-11	3.63E-10	9.52E-10	Not detected
	Feb. 10 – Feb. 24	2.14E-10	2.03E-10	3.32E-10	Not detected
	Feb. 24 – Mar. 9	1.88E-10	2.66E-10	5.62E-10	Not detected
	Mar. 9 – Mar. 23	5.43E-10	3.22E-10	4.34E-10	Detected
	Mar. 23 – Apr. 6	1.06E-09	4.09E-10	3.19E-10	Detected
	Apr. 6 – Apr. 26	3.24E-10	2.02E-10	3.04E-10	Detected
	Apr. 26 – May 9	2.77E-10	2.88E-10	5.59E-10	Not detected
	May 9 – May 25	-1.64E-10	3.64E-10	1.00E-09	Not detected
	May 25 – Jun. 16	3.33E-11	1.97E-11	2.67E-11	Detected
	Jun. 16 – Jul. 8	3.53E-10	2.20E-10	3.50E-10	Detected
	Jul. 8 – Jul. 20	5.87E-10	4.39E-10	7.88E-10	Not detected
	Jul. 20 – Jul. 27	-2.76E-10	4.89E-10	1.61E-09	Not detected
	Jul. 27 - Aug. 23	2.78E-10	1.97E-10	3.46E-10	Not detected
	Aug. 23 – Sep. 30	0.00E+00	4.79E-11	1.56E-11	Not detected
	Sep. 30 – Oct. 24	2.24E-10	1.88E-10	3.55E-10	Not detected
	Oct. 24 – Nov. 29	3.86E-10	2.93E-10	4.64E-10	Not detected
	Nov. 29 – Dec. 21	2.20E-10	1.93E-10	3.76E-10	Not detected
	Dec. 21 – Jan. 6	1.67E-10	2.06E-10	3.88E-10	Not detected

Table 3-31: Activity concentrations of ^{241}Am, $^{239+240}Pu$ and ^{238}Pu in the filter samples collected from Loving Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{238}Pu	Jan. 8 – Jan. 27	-1.26E-09	7.56E-09	2.20E-08	Not detected
	Jan. 27 – Feb. 10	-1.93E-09	5.46E-09	1.79E-08	Not detected
	Feb. 10 – Feb. 24	-1.26E-09	9.79E-09	2.68E-08	Not detected
	Feb. 24 – Mar. 9	4.96E-09	6.64E-09	1.22E-08	Not detected
	Mar. 9 – Mar. 23	-7.67E-09	8.13E-09	2.72E-08	Not detected
	Mar. 23 – Apr. 6	1.21E-09	4.18E-09	1.13E-08	Not detected
	Apr. 6 – Apr. 26	-3.05E-09	3.75E-09	1.33E-08	Not detected
	Apr. 26 – May 9	-1.40E-09	6.26E-09	1.97E-08	Not detected
	May 9 – May 25	-5.77E-09	7.68E-09	2.46E-08	Not detected
	May 25 – Jun. 16	-2.36E-10	4.72E-10	1.48E-09	Not detected
	Jun. 16 – Jul. 8	0.00E+00	6.21E-09	1.66E-08	Not detected
	Jul. 8 – Jul. 20	-6.38E-09	7.84E-09	2.78E-08	Not detected
	Jul. 20 – Jul. 27	-6.51E-09	1.84E-08	5.67E-08	Not detected
	Jul. 27 - Aug. 23	-6.67E-16	4.43E-09	1.22E-08	Not detected
	Aug. 23 – Sep. 30	-1.69E-09	2.40E-09	7.94E-09	Not detected
	Sep. 30 – Oct. 24	7.18E-10	4.32E-09	1.14E-08	Not detected
	Oct. 24 – Nov. 29	9.76E-16	7.71E-09	2.16E-08	Not detected
	Nov. 29 – Dec. 21	-7.09E-09	6.03E-09	1.93E-08	Not detected
	Dec. 21 – Jan. 6	-4.43E-09	1.14E-08	3.32E-08	Not detected

Table 3-32: Activity concentrations of ^{241}Am, $^{239+240}Pu$ and ^{238}Pu in the filter samples collected from Carlsbad Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{241}Am	Jan. 8 – Jan. 27	3.19E-09	5.07E-09	1.13E-08	Not detected
	Jan. 27 – Feb. 10	1.18E-08	1.00E-08	1.96E-08	Not detected
	Feb. 10 – Feb. 24	6.21E-09	1.46E-08	3.49E-08	Not detected
	Feb. 24 – Mar. 9	2.20E-08	1.01E-08	7.72E-09	Detected
	Mar. 9 – Mar. 23	1.72E-08	9.87E-09	1.52E-08	Detected
	Mar. 23 – Apr. 6	2.20E-08	1.15E-08	1.66E-08	Detected
	Apr. 6 – Apr. 26	-2.27E-09	4.00E-09	1.32E-08	Not detected
	Apr. 26 – May 9	1.24E-08	1.19E-08	2.41E-08	Not detected
	May 9 – May 25	1.53E-08	8.79E-09	1.35E-08	Detected
	May 25 – Jun. 16	1.13E-08	6.75E-09	1.06E-08	Detected
	Jun. 16 – Jul. 8	5.23E-09	9.13E-09	2.10E-08	Not detected
	Jul. 8 – Jul. 20	1.31E-09	1.31E-08	3.35E-08	Not detected
	Jul. 20 – Jul. 27	4.03E-08	2.17E-08	2.99E-08	Detected

Table 3-32: Activity concentrations of ^{241}Am, $^{239+240}Pu$ and ^{238}Pu in the filter samples collected from Carlsbad Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{241}Am	Jul. 27 - Aug. 23	4.23E-09	5.03E-09	1.05E-08	Not detected
	Aug. 23 – Sep. 30	7.02E-09	4.31E-09	6.01E-09	Detected
	Sep. 30 – Oct. 24	4.81E-09	5.69E-09	1.21E-08	Not detected
	Oct. 24 – Nov. 29	4.97E-09	3.71E-09	6.67E-09	Not detected
	Nov. 29 – Dec. 21	-3.63E-09	1.62E-08	4.46E-08	Not detected
	Dec. 21 – Jan. 6	5.20E-09	7.38E-09	1.63E-08	Not detected
$^{239+240}Pu$	Jan. 8 – Jan. 27	-3.65E-09	7.32E-09	2.29E-08	Not detected
	Jan. 27 – Feb. 10	1.50E-08	1.55E-08	3.02E-08	Not detected
	Feb. 10 – Feb. 24	7.40E-09	8.58E-09	1.74E-08	Not detected
	Feb. 24 – Mar. 9	6.83E-09	2.08E-08	5.11E-08	Not detected
	Mar. 9 – Mar. 23	2.19E-08	1.37E-08	2.25E-08	Not detected
	Mar. 23 – Apr. 6	1.82E-08	1.17E-08	1.68E-08	Detected
	Apr. 6 – Apr. 26	6.89E-09	8.61E-09	1.88E-08	Not detected
	Apr. 26 – May 9	1.87E-08	1.16E-08	1.61E-08	Detected
	May 9 – May 25	1.13E-08	9.18E-09	1.60E-08	Not detected
	May 25 – Jun. 16	1.20E-08	1.04E-08	2.07E-08	Not detected
	Jun. 16 – Jul. 8	2.38E-08	9.37E-09	7.39E-09	Detected
	Jul. 8 – Jul. 20	1.21E-08	9.81E-09	1.62E-08	Not detected
	Jul. 20 – Jul. 27	2.10E-08	1.99E-08	3.59E-08	Not detected
	Jul. 27 - Aug. 23	7.54E-09	5.70E-09	9.04E-09	Not detected
	Aug. 23 – Sep. 30	1.94E-09	2.75E-09	5.82E-09	Not detected
	Sep. 30 – Oct. 24	6.14E-09	5.33E-09	9.19E-09	Not detected
	Oct. 24 – Nov. 29	1.04E-08	1.23E-08	2.58E-08	Not detected
	Nov. 29 – Dec. 21	1.13E-08	1.11E-08	2.19E-08	Not detected
	Dec. 21 – Jan. 6	5.69E-09	6.86E-09	1.37E-08	Not detected
^{238}Pu	Jan. 8 – Jan. 27	2.44E-09	4.88E-09	1.13E-08	Not detected
	Jan. 27 – Feb. 10	6.42E-09	9.56E-09	1.99E-08	Not detected
	Feb. 10 – Feb. 24	-1.23E-09	8.18E-09	2.32E-08	Not detected
	Feb. 24 – Mar. 9	-2.28E-09	1.02E-08	3.21E-08	Not detected
	Mar. 9 – Mar. 23	2.58E-09	8.18E-09	2.05E-08	Not detected
	Mar. 23 – Apr. 6	4.19E-09	1.15E-08	2.81E-08	Not detected
	Apr. 6 – Apr. 26	-9.96E-09	8.36E-09	2.52E-08	Not detected
	Apr. 26 – May 9	1.34E-09	5.99E-09	1.61E-08	Not detected
	May 9 – May 25	1.13E-09	8.79E-09	2.28E-08	Not detected
	May 25 – Jun. 16	-9.25E-09	8.32E-09	2.60E-08	Not detected
	Jun. 16 – Jul. 8	-3.98E-09	6.19E-09	1.87E-08	Not detected

Table 3-32: Activity concentrations of ^{241}Am, $^{239+240}$Pu and ^{238}Pu in the filter samples collected from Carlsbad Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{238}Pu	Jul. 8 – Jul. 20	8.09E-09	8.57E-09	1.62E-08	Not detected
	Jul. 20 – Jul. 27	1.80E-08	1.90E-08	3.59E-08	Not detected
	Jul. 27 - Aug. 23	6.77E-09	5.46E-09	9.04E-09	Not detected
	Aug. 23 – Sep. 30	3.40E-09	3.78E-09	7.71E-09	Not detected
	Sep. 30 – Oct. 24	-7.67E-10	3.42E-09	1.08E-08	Not detected
	Oct. 24 – Nov. 29	-2.97E-09	7.28E-09	2.35E-08	Not detected
	Nov. 29 – Dec. 21	0.00E+00	5.04E-09	1.51E-08	Not detected
	Dec. 21 – Jan. 6	-6.83E-09	9.73E-09	2.90E-08	Not detected

Table 3-33: Activity Density of ^{241}Am, $^{239+240}$Pu and ^{238}Pu in the filter samples collected from Loving Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{241}Am	Jan. 8 – Jan. 27	3.00E-04	1.78E-04	2.40E-04	Detected
	Jan. 27 – Feb. 10	4.23E-04	2.81E-04	5.01E-04	Not detected
	Feb. 10 – Feb. 24	4.37E-04	2.51E-04	4.01E-04	Detected
	Feb. 24 – Mar. 9	3.41E-04	1.91E-04	2.10E-04	Detected
	Mar. 9 – Mar. 23	2.99E-04	1.71E-04	2.47E-04	Detected
	Mar. 23 – Apr. 6	2.31E-04	1.13E-04	1.32E-04	Detected
	Apr. 6 – Apr. 26	3.13E-04	1.32E-04	1.12E-04	Detected
	Apr. 26 – May 9	6.67E-05	9.47E-05	2.00E-04	Not detected
	May 9 – May 25	1.48E-04	1.36E-04	2.60E-04	Not detected
	May 25 – Jun. 16	8.81E-05	7.69E-05	1.32E-04	Not detected
	Jun. 16 – Jul. 8	2.57E-04	1.35E-04	1.41E-04	Detected
	Jul. 8 – Jul. 20	4.34E-04	2.78E-04	4.81E-04	Not detected
	Jul. 20 – Jul. 27	4.13E-04	3.73E-04	7.17E-04	Not detected
	Jul. 27 - Aug. 23	1.93E-04	1.11E-04	1.60E-04	Detected
	Aug. 23 – Sep. 30	9.88E-05	9.63E-05	1.91E-04	Not detected
	Sep. 30 – Oct. 24	1.45E-04	1.38E-04	2.85E-04	Not detected
	Oct. 24 – Nov. 29	1.95E-04	1.12E-04	1.79E-04	Detected
	Nov. 29 – Dec. 21	1.20E-04	1.54E-04	3.37E-04	Not detected
	Dec. 21 – Jan. 6	7.57E-04	4.34E-04	7.11E-04	Detected
$^{239+240}$Pu	Jan. 8 – Jan. 27	-3.27E-05	2.53E-04	6.98E-04	Not detected
	Jan. 27 – Feb. 10	4.39E-05	2.91E-04	7.64E-04	Not detected
	Feb. 10 – Feb. 24	1.75E-04	1.66E-04	2.71E-04	Not detected
	Feb. 24 – Mar. 9	1.47E-04	2.08E-04	4.40E-04	Not detected

Table 3-33: Activity Density of ^{241}Am, $^{239+240}Pu$ and ^{238}Pu in the filter samples collected from Loving Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
$^{239+240}Pu$	Mar. 9 – Mar. 23	3.34E-04	1.98E-04	2.67E-04	Detected
	Mar. 23 – Apr. 6	4.19E-04	1.62E-04	1.26E-04	Detected
	Apr. 6 – Apr. 26	2.08E-04	1.30E-04	1.96E-04	Detected
	Apr. 26 – May 9	1.28E-04	1.33E-04	2.58E-04	Not detected
	May 9 – May 25	-1.07E-04	2.37E-04	6.54E-04	Not detected
	May 25 – Jun. 16	1.99E-04	1.18E-04	1.59E-04	Detected
	Jun. 16 – Jul. 8	2.76E-04	1.72E-04	2.73E-04	Detected
	Jul. 8 – Jul. 20	3.48E-04	2.60E-04	4.67E-04	Not detected
	Jul. 20 – Jul. 27	-2.05E-04	3.63E-04	1.19E-03	Not detected
	Jul. 27 - Aug. 23	1.95E-04	1.38E-04	2.42E-04	Not detected
	Aug. 23 – Sep. 30	0.00E+00	5.41E-05	1.76E-05	Not detected
	Sep. 30 – Oct. 24	1.66E-04	1.39E-04	2.63E-04	Not detected
	Oct. 24 – Nov. 29	3.38E-04	2.56E-04	4.07E-04	Not detected
	Nov. 29 – Dec. 21	1.82E-04	1.59E-04	3.11E-04	Not detected
	Dec. 21 – Jan. 6	2.54E-04	3.12E-04	5.89E-04	Not detected
^{238}Pu	Jan. 8 – Jan. 27	-3.27E-05	1.96E-04	5.70E-04	Not detected
	Jan. 27 – Feb. 10	-4.39E-05	1.24E-04	4.07E-04	Not detected
	Feb. 10 – Feb. 24	-2.91E-05	2.27E-04	6.21E-04	Not detected
	Feb. 24 – Mar. 9	1.10E-04	1.47E-04	2.71E-04	Not detected
	Mar. 9 – Mar. 23	-1.34E-04	1.42E-04	4.75E-04	Not detected
	Mar. 23 – Apr. 6	1.35E-05	4.68E-05	1.26E-04	Not detected
	Apr. 6 – Apr. 26	-5.56E-05	6.84E-05	2.42E-04	Not detected
	Apr. 26 – May 9	-1.83E-05	8.18E-05	2.58E-04	Not detected
	May 9 – May 25	-1.07E-04	1.42E-04	4.55E-04	Not detected
	May 25 – Jun. 16	-3.99E-05	7.99E-05	2.50E-04	Not detected
	Jun. 16 – Jul. 8	0.00E+00	1.37E-04	3.67E-04	Not detected
	Jul. 8 – Jul. 20	-1.07E-04	1.32E-04	4.67E-04	Not detected
	Jul. 20 – Jul. 27	-1.37E-04	3.88E-04	1.19E-03	Not detected
	Jul. 27 - Aug. 23	-1.32E-11	8.79E-05	2.42E-04	Not detected
	Aug. 23 – Sep. 30	-5.41E-05	7.68E-05	2.54E-04	Not detected
	Sep. 30 – Oct. 24	1.50E-05	9.04E-05	2.39E-04	Not detected
	Oct. 24 – Nov. 29	2.42E-11	1.91E-04	5.37E-04	Not detected
	Nov. 29 – Dec. 21	-1.66E-04	1.41E-04	4.52E-04	Not detected
	Dec. 21 – Jan. 6	-1.90E-04	4.90E-04	1.42E-03	Not detected

Table 3-34: Activity Density of ^{241}Am, $^{239+240}Pu$ and ^{238}Pu in the filter samples collected from Carlsbad Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{241}Am	Jan. 8 – Jan. 27	1.86E-04	2.95E-04	6.55E-04	Not detected
	Jan. 27 – Feb. 10	5.37E-04	4.57E-04	8.98E-04	Not detected
	Feb. 10 – Feb. 24	1.94E-04	4.56E-04	1.09E-03	Not detected
	Feb. 24 – Mar. 9	6.34E-04	2.90E-04	2.22E-04	Detected
	Mar. 9 – Mar. 23	4.09E-04	2.35E-04	3.61E-04	Detected
	Mar. 23 – Apr. 6	3.82E-04	2.00E-04	2.89E-04	Detected
	Apr. 6 – Apr. 26	-6.35E-05	1.12E-04	3.68E-04	Not detected
	Apr. 26 – May 9	2.37E-04	2.26E-04	4.59E-04	Not detected
	May 9 – May 25	2.81E-04	1.62E-04	2.49E-04	Detected
	May 25 – Jun. 16	2.64E-04	1.57E-04	2.46E-04	Detected
	Jun. 16 – Jul. 8	1.29E-04	2.26E-04	5.20E-04	Not detected
	Jul. 8 – Jul. 20	2.44E-05	2.44E-04	6.23E-04	Not detected
	Jul. 20 – Jul. 27	9.56E-04	5.14E-04	7.10E-04	Detected
	Jul. 27 - Aug. 23	1.27E-04	1.51E-04	3.16E-04	Not detected
	Aug. 23 – Sep. 30	2.90E-04	1.78E-04	2.48E-04	Detected
	Sep. 30 – Oct. 24	1.38E-04	1.64E-04	3.47E-04	Not detected
	Oct. 24 – Nov. 29	1.93E-04	1.44E-04	2.59E-04	Not detected
	Nov. 29 – Dec. 21	-1.18E-04	5.27E-04	1.45E-03	Not detected
	Dec. 21 – Jan. 6	2.81E-04	3.99E-04	8.82E-04	Not detected
$^{239+240}Pu$	Jan. 8 – Jan. 27	-2.12E-04	4.26E-04	1.33E-03	Not detected
	Jan. 27 – Feb. 10	6.85E-04	7.09E-04	1.38E-03	Not detected
	Feb. 10 – Feb. 24	2.31E-04	2.68E-04	5.44E-04	Not detected
	Feb. 24 – Mar. 9	1.97E-04	6.01E-04	1.47E-03	Not detected
	Mar. 9 – Mar. 23	5.22E-04	3.25E-04	5.35E-04	Not detected
	Mar. 23 – Apr. 6	3.16E-04	2.03E-04	2.92E-04	Detected
	Apr. 6 – Apr. 26	1.93E-04	2.41E-04	5.27E-04	Not detected
	Apr. 26 – May 9	3.57E-04	2.20E-04	3.06E-04	Detected
	May 9 – May 25	2.09E-04	1.69E-04	2.94E-04	Not detected
	May 25 – Jun. 16	2.78E-04	2.41E-04	4.81E-04	Not detected
	Jun. 16 – Jul. 8	5.90E-04	2.32E-04	1.83E-04	Detected
	Jul. 8 – Jul. 20	2.26E-04	1.82E-04	3.02E-04	Not detected
	Jul. 20 – Jul. 27	4.97E-04	4.72E-04	8.52E-04	Not detected
	Jul. 27 - Aug. 23	2.26E-04	1.71E-04	2.71E-04	Not detected
	Aug. 23 – Sep. 30	8.01E-05	1.14E-04	2.40E-04	Not detected
	Sep. 30 – Oct. 24	1.77E-04	1.53E-04	2.64E-04	Not detected
	Oct. 24 – Nov. 29	4.05E-04	4.79E-04	1.01E-03	Not detected
	Nov. 29 – Dec. 21	3.68E-04	3.59E-04	7.12E-04	Not detected
	Dec. 21 – Jan. 6	3.08E-04	3.71E-04	7.41E-04	Not detected

Table 3-34: Activity Density of ^{241}Am, $^{239+240}Pu$ and ^{238}Pu in the filter samples collected from Carlsbad Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{238}Pu	Jan. 8 – Jan. 27	1.42E-04	2.84E-04	6.59E-04	Not detected
	Jan. 27 – Feb. 10	2.93E-04	4.37E-04	9.10E-04	Not detected
	Feb. 10 – Feb. 24	-3.85E-05	2.56E-04	7.27E-04	Not detected
	Feb. 24 – Mar. 9	-6.56E-05	2.93E-04	9.24E-04	Not detected
	Mar. 9 – Mar. 23	6.14E-05	1.95E-04	4.88E-04	Not detected
	Mar. 23 – Apr. 6	7.28E-05	2.00E-04	4.89E-04	Not detected
	Apr. 6 – Apr. 26	-2.79E-04	2.34E-04	7.06E-04	Not detected
	Apr. 26 – May 9	2.55E-05	1.14E-04	3.06E-04	Not detected
	May 9 – May 25	2.09E-05	1.62E-04	4.21E-04	Not detected
	May 25 – Jun. 16	-2.15E-04	1.93E-04	6.04E-04	Not detected
	Jun. 16 – Jul. 8	-9.84E-05	1.53E-04	4.62E-04	Not detected
	Jul. 8 – Jul. 20	1.50E-04	1.59E-04	3.02E-04	Not detected
	Jul. 20 – Jul. 27	4.26E-04	4.51E-04	8.52E-04	Not detected
	Jul. 27 - Aug. 23	2.03E-04	1.64E-04	2.71E-04	Not detected
	Aug. 23 – Sep. 30	1.40E-04	1.56E-04	3.18E-04	Not detected
	Sep. 30 – Oct. 24	-2.20E-05	9.84E-05	3.11E-04	Not detected
	Oct. 24 – Nov. 29	-1.15E-04	2.83E-04	9.15E-04	Not detected
	Nov. 29 – Dec. 21	0.00E+00	1.64E-04	4.92E-04	Not detected
	Dec. 21 – Jan. 6	-3.69E-04	5.26E-04	1.57E-03	Not detected

Table 3-35: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Loving Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{234}U	Jan. 8 – Jan. 27	1.26E-06	2.21E-07	2.02E-08	Detected
	Jan. 27 – Feb. 10	1.13E-06	2.47E-07	2.69E-08	Detected
	Feb. 10 – Feb. 24	1.41E-06	2.71E-07	1.99E-08	Detected
	Feb. 24 – Mar. 9	1.64E-06	2.95E-07	2.30E-08	Detected
	Mar. 9 – Mar. 23	1.39E-06	2.74E-07	5.31E-08	Detected
	Mar. 23 – Apr. 6	2.38E-06	3.83E-07	3.17E-08	Detected
	Apr. 6 – Apr. 26	1.56E-06	2.53E-07	2.30E-08	Detected
	Apr. 26 – May 9	2.61E-06	4.01E-07	2.78E-08	Detected
	May 9 – May 25	1.68E-06	2.76E-07	2.45E-08	Detected
	May 25 – Jun. 16	1.55E-07	2.37E-08	1.44E-09	Detected
	Jun. 16 – Jul. 8	1.34E-06	2.23E-07	2.15E-08	Detected
	Jul. 8 – Jul. 20	2.12E-06	4.00E-07	4.33E-08	Detected
	Jul. 20 – Jul. 27	1.73E-06	4.18E-07	3.01E-08	Detected

Table 3-35: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Loving Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{234}U	Jul. 27 - Aug. 23	1.30E-06	2.03E-07	6.92E-09	Detected
	Aug. 23 – Sep. 30	6.02E-07	1.03E-07	8.07E-09	Detected
	Sep. 30 – Oct. 24	1.08E-06	1.81E-07	1.37E-08	Detected
	Oct. 24 – Nov. 29	9.88E-07	1.49E-07	1.03E-08	Detected
	Nov. 29 – Dec. 21	1.21E-06	2.07E-07	1.79E-08	Detected
	Dec. 21 – Jan. 6	8.45E-07	1.89E-07	2.60E-08	Detected
^{235}U	Jan. 8 – Jan. 27	6.37E-08	2.70E-08	2.01E-08	Detected
	Jan. 27 – Feb. 10	4.71E-08	3.30E-08	2.83E-08	Detected
	Feb. 10 – Feb. 24	8.71E-08	3.71E-08	2.46E-08	Detected
	Feb. 24 – Mar. 9	1.02E-07	3.96E-08	2.85E-08	Detected
	Mar. 9 – Mar. 23	7.32E-08	3.66E-08	2.71E-08	Detected
	Mar. 23 – Apr. 6	1.61E-07	5.03E-08	3.17E-08	Detected
	Apr. 6 – Apr. 26	1.49E-07	3.84E-08	1.98E-08	Detected
	Apr. 26 – May 9	9.16E-08	3.79E-08	3.43E-08	Detected
	May 9 – May 25	9.66E-08	3.18E-08	1.31E-08	Detected
	May 25 – Jun. 16	7.39E-09	2.37E-09	9.47E-10	Detected
	Jun. 16 – Jul. 8	6.65E-08	2.57E-08	1.58E-08	Detected
	Jul. 8 – Jul. 20	1.20E-07	5.47E-08	5.36E-08	Detected
	Jul. 20 – Jul. 27	1.44E-07	7.15E-08	6.98E-08	Detected
	Jul. 27 - Aug. 23	4.97E-08	1.95E-08	1.60E-08	Detected
	Aug. 23 – Sep. 30	2.33E-08	1.12E-08	7.53E-09	Detected
	Sep. 30 – Oct. 24	3.44E-08	1.73E-08	8.99E-09	Detected
	Oct. 24 – Nov. 29	3.04E-08	1.25E-08	9.43E-09	Detected
	Nov. 29 – Dec. 21	3.78E-08	2.03E-08	1.18E-08	Detected
	Dec. 21 – Jan. 6	1.81E-08	2.14E-08	1.91E-08	Not detected
^{238}U	Jan. 8 – Jan. 27	1.05E-06	1.99E-07	2.82E-08	Detected
	Jan. 27 – Feb. 10	9.85E-07	2.30E-07	4.26E-08	Detected
	Feb. 10 – Feb. 24	1.24E-06	2.52E-07	2.88E-08	Detected
	Feb. 24 – Mar. 9	1.60E-06	2.91E-07	2.58E-08	Detected
	Mar. 9 – Mar. 23	1.38E-06	2.71E-07	6.37E-08	Detected
	Mar. 23 – Apr. 6	2.34E-06	3.79E-07	3.64E-08	Detected
	Apr. 6 – Apr. 26	1.52E-06	2.48E-07	3.39E-08	Detected
	Apr. 26 – May 9	2.43E-06	3.82E-07	2.34E-08	Detected
	May 9 – May 25	1.51E-06	2.58E-07	2.68E-08	Detected
	May 25 – Jun. 16	1.46E-07	2.28E-08	2.02E-09	Detected
	Jun. 16 – Jul. 8	1.15E-06	2.01E-07	2.50E-08	Detected
	Jul. 8 – Jul. 20	2.00E-06	3.89E-07	5.63E-08	Detected

Table 3-35: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Loving Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{238}U	Jul. 20 – Jul. 27	1.88E-06	4.35E-07	6.89E-08	Detected
	Jul. 27 - Aug. 23	1.21E-06	1.92E-07	1.58E-08	Detected
	Aug. 23 – Sep. 30	5.45E-07	9.75E-08	1.14E-08	Detected
	Sep. 30 – Oct. 24	9.32E-07	1.66E-07	1.36E-08	Detected
	Oct. 24 – Nov. 29	8.98E-07	1.40E-07	1.22E-08	Detected
	Nov. 29 – Dec. 21	1.02E-06	1.86E-07	3.14E-08	Detected
	Dec. 21 – Jan. 6	7.29E-07	1.77E-07	3.52E-08	Detected

Table 3-36: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Carlsbad Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{234}U	Jan. 8 – Jan. 27	7.14E-07	1.61E-07	1.76E-08	Detected
	Jan. 27 – Feb. 10	8.27E-07	2.19E-07	4.15E-08	Detected
	Feb. 10 – Feb. 24	1.29E-06	2.57E-07	2.36E-08	Detected
	Feb. 24 – Mar. 9	1.12E-06	2.48E-07	1.86E-08	Detected
	Mar. 9 – Mar. 23	1.46E-06	2.77E-07	2.70E-08	Detected
	Mar. 23 – Apr. 6	1.60E-06	2.94E-07	1.65E-08	Detected
	Apr. 6 – Apr. 26	1.16E-06	2.06E-07	2.14E-08	Detected
	Apr. 26 – May 9	1.61E-06	2.99E-07	2.39E-08	Detected
	May 9 – May 25	9.81E-07	2.04E-07	2.69E-08	Detected
	May 25 – Jun. 16	1.22E-06	2.07E-07	2.11E-08	Detected
	Jun. 16 – Jul. 8	1.11E-06	2.02E-07	2.29E-08	Detected
	Jul. 8 – Jul. 20	1.60E-06	3.11E-07	4.20E-08	Detected
	Jul. 20 – Jul. 27	1.92E-06	4.30E-07	4.49E-08	Detected
	Jul. 27 - Aug. 23	9.34E-07	1.61E-07	1.17E-08	Detected
	Aug. 23 – Sep. 30	4.60E-07	9.98E-08	1.55E-08	Detected
	Sep. 30 – Oct. 24	6.97E-07	1.46E-07	1.47E-08	Detected
	Oct. 24 – Nov. 29	6.54E-07	1.13E-07	1.07E-08	Detected
	Nov. 29 – Dec. 21	9.00E-07	1.69E-07	2.27E-08	Detected
	Dec. 21 – Jan. 6	6.30E-07	1.62E-07	2.57E-08	Detected
^{235}U	Jan. 8 – Jan. 27	1.76E-08	1.87E-08	1.65E-08	Detected
	Jan. 27 – Feb. 10	1.52E-07	5.29E-08	3.27E-08	Detected
	Feb. 10 – Feb. 24	4.86E-08	3.05E-08	1.92E-08	Detected
	Feb. 24 – Mar. 9	1.86E-07	5.62E-08	3.50E-08	Detected
	Mar. 9 – Mar. 23	5.17E-08	3.24E-08	2.96E-08	Detected
	Mar. 23 – Apr. 6	6.91E-08	3.55E-08	2.63E-08	Detected

Table 3-36: Activity concentrations of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Carlsbad Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{235}U	Apr. 6 – Apr. 26	3.91E-08	2.20E-08	1.85E-08	Detected
	Apr. 26 – May 9	7.04E-08	3.47E-08	1.54E-08	Detected
	May 9 – May 25	6.30E-08	2.86E-08	1.87E-08	Detected
	May 25 – Jun. 16	8.59E-08	2.72E-08	1.64E-08	Detected
	Jun. 16 – Jul. 8	5.92E-08	2.58E-08	1.98E-08	Detected
	Jul. 8 – Jul. 20	1.73E-07	5.30E-08	3.50E-08	Detected
	Jul. 20 – Jul. 27	1.09E-07	5.92E-08	4.19E-08	Detected
	Jul. 27 - Aug. 23	4.19E-08	1.77E-08	1.10E-08	Detected
	Aug. 23 – Sep. 30	2.60E-08	1.52E-08	1.32E-08	Detected
	Sep. 30 – Oct. 24	3.84E-08	2.10E-08	2.04E-08	Detected
	Oct. 24 – Nov. 29	3.25E-08	1.26E-08	5.75E-09	Detected
	Nov. 29 – Dec. 21	3.38E-08	1.87E-08	1.49E-08	Detected
	Dec. 21 – Jan. 6	3.13E-08	2.21E-08	1.31E-08	Detected
^{238}U	Jan. 8 – Jan. 27	6.17E-07	1.50E-07	2.23E-08	Detected
	Jan. 27 – Feb. 10	9.23E-07	2.31E-07	5.17E-08	Detected
	Feb. 10 – Feb. 24	1.39E-06	2.69E-07	2.35E-08	Detected
	Feb. 24 – Mar. 9	1.03E-06	2.37E-07	4.03E-08	Detected
	Mar. 9 – Mar. 23	1.47E-06	3.24E-08	2.96E-08	Detected
	Mar. 23 – Apr. 6	1.44E-06	2.77E-07	3.56E-08	Detected
	Apr. 6 – Apr. 26	9.98E-07	1.89E-07	3.08E-08	Detected
	Apr. 26 – May 9	1.50E-06	2.88E-07	3.78E-08	Detected
	May 9 – May 25	9.50E-07	2.01E-07	3.75E-08	Detected
	May 25 – Jun. 16	1.13E-06	1.96E-07	1.76E-08	Detected
	Jun. 16 – Jul. 8	1.14E-06	2.05E-07	2.28E-08	Detected
	Jul. 8 – Jul. 20	1.64E-06	3.15E-07	4.53E-08	Detected
	Jul. 20 – Jul. 27	1.62E-06	3.96E-07	7.18E-08	Detected
	Jul. 27 - Aug. 23	9.44E-07	1.62E-07	1.88E-08	Detected
	Aug. 23 – Sep. 30	4.54E-07	4.31E-09	6.01E-09	Detected
	Sep. 30 – Oct. 24	6.76E-07	5.69E-09	1.21E-08	Detected
	Oct. 24 – Nov. 29	6.50E-07	3.71E-09	6.67E-09	Detected
	Nov. 29 – Dec. 21	8.76E-07	1.62E-08	4.46E-08	Detected
	Dec. 21 – Jan. 6	7.14E-07	7.38E-09	1.63E-08	Detected

Table 3-37: Activity density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Loving Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{234}U	Jan. 8 – Jan. 27	3.26E-02	5.74E-03	5.23E-04	Detected
	Jan. 27 – Feb. 10	2.58E-02	5.63E-03	6.13E-04	Detected
	Feb. 10 – Feb. 24	3.26E-02	6.28E-03	4.62E-04	Detected
	Feb. 24 – Mar. 9	3.63E-02	6.54E-03	5.10E-04	Detected
	Mar. 9 – Mar. 23	2.43E-02	4.78E-03	9.25E-04	Detected
	Mar. 23 – Apr. 6	2.66E-02	4.29E-03	3.54E-04	Detected
	Apr. 6 – Apr. 26	2.85E-02	4.61E-03	4.19E-04	Detected
	Apr. 26 – May 9	3.41E-02	5.24E-03	3.63E-04	Detected
	May 9 – May 25	3.10E-02	5.10E-03	4.52E-04	Detected
	May 25 – Jun. 16	2.62E-02	4.02E-03	2.44E-04	Detected
	Jun. 16 – Jul. 8	2.95E-02	4.92E-03	4.74E-04	Detected
	Jul. 8 – Jul. 20	3.56E-02	6.73E-03	7.28E-04	Detected
	Jul. 20 – Jul. 27	3.63E-02	8.78E-03	6.33E-04	Detected
	Jul. 27 - Aug. 23	2.58E-02	4.02E-03	1.37E-04	Detected
	Aug. 23 – Sep. 30	1.93E-02	3.30E-03	2.58E-04	Detected
	Sep. 30 – Oct. 24	2.25E-02	3.80E-03	2.86E-04	Detected
	Oct. 24 – Nov. 29	2.45E-02	3.70E-03	2.55E-04	Detected
	Nov. 29 – Dec. 21	2.84E-02	4.83E-03	4.19E-04	Detected
	Dec. 21 – Jan. 6	3.63E-02	8.13E-03	1.12E-03	Detected
^{235}U	Jan. 8 – Jan. 27	1.66E-03	7.01E-04	5.22E-04	Detected
	Jan. 27 – Feb. 10	1.07E-03	7.50E-04	6.43E-04	Detected
	Feb. 10 – Feb. 24	2.02E-03	8.60E-04	5.71E-04	Detected
	Feb. 24 – Mar. 9	2.27E-03	8.78E-04	6.31E-04	Detected
	Mar. 9 – Mar. 23	1.28E-03	6.38E-04	4.73E-04	Detected
	Mar. 23 – Apr. 6	1.80E-03	5.63E-04	3.54E-04	Detected
	Apr. 6 – Apr. 26	2.72E-03	6.99E-04	3.61E-04	Detected
	Apr. 26 – May 9	1.20E-03	4.95E-04	4.48E-04	Detected
	May 9 – May 25	1.79E-03	5.88E-04	2.43E-04	Detected
	May 25 – Jun. 16	1.25E-03	4.02E-04	1.60E-04	Detected
	Jun. 16 – Jul. 8	1.47E-03	5.67E-04	3.49E-04	Detected
	Jul. 8 – Jul. 20	2.02E-03	9.20E-04	9.00E-04	Detected
	Jul. 20 – Jul. 27	3.02E-03	1.50E-03	1.47E-03	Detected
	Jul. 27 - Aug. 23	9.86E-04	3.87E-04	3.16E-04	Detected
	Aug. 23 – Sep. 30	7.46E-04	3.59E-04	2.41E-04	Detected
	Sep. 30 – Oct. 24	7.20E-04	3.62E-04	1.88E-04	Detected
	Oct. 24 – Nov. 29	7.53E-04	3.11E-04	2.34E-04	Detected
	Nov. 29 – Dec. 21	8.84E-04	4.74E-04	2.76E-04	Detected
	Dec. 21 – Jan. 6	7.78E-04	9.21E-04	8.22E-04	Not detected

Table 3-37: Activity density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Loving Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{238}U	Jan. 8 – Jan. 27	2.74E-02	5.17E-03	7.33E-04	Detected
	Jan. 27 – Feb. 10	2.24E-02	5.23E-03	9.70E-04	Detected
	Feb. 10 – Feb. 24	2.88E-02	5.83E-03	6.68E-04	Detected
	Feb. 24 – Mar. 9	3.55E-02	6.45E-03	5.73E-04	Detected
	Mar. 9 – Mar. 23	2.40E-02	4.73E-03	1.11E-03	Detected
	Mar. 23 – Apr. 6	2.62E-02	4.25E-03	4.08E-04	Detected
	Apr. 6 – Apr. 26	2.77E-02	4.52E-03	6.18E-04	Detected
	Apr. 26 – May 9	3.17E-02	4.99E-03	3.05E-04	Detected
	May 9 – May 25	2.79E-02	4.76E-03	4.96E-04	Detected
	May 25 – Jun. 16	2.47E-02	3.86E-03	3.43E-04	Detected
	Jun. 16 – Jul. 8	2.53E-02	4.45E-03	5.53E-04	Detected
	Jul. 8 – Jul. 20	3.36E-02	6.53E-03	9.46E-04	Detected
	Jul. 20 – Jul. 27	3.96E-02	9.14E-03	1.45E-03	Detected
	Jul. 27 - Aug. 23	2.39E-02	3.81E-03	3.12E-04	Detected
	Aug. 23 – Sep. 30	1.75E-02	3.12E-03	3.64E-04	Detected
	Sep. 30 – Oct. 24	1.95E-02	3.47E-03	2.85E-04	Detected
	Oct. 24 – Nov. 29	2.23E-02	3.46E-03	3.04E-04	Detected
	Nov. 29 – Dec. 21	2.39E-02	4.35E-03	7.34E-04	Detected
	Dec. 21 – Jan. 6	3.13E-02	7.60E-03	1.51E-03	Detected

Table 3-38: Activity density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Carlsbad Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{234}U	Jan. 8 – Jan. 27	4.15E-02	9.34E-03	1.02E-03	Detected
	Jan. 27 – Feb. 10	3.78E-02	1.00E-02	1.90E-03	Detected
	Feb. 10 – Feb. 24	4.02E-02	8.03E-03	7.38E-04	Detected
	Feb. 24 – Mar. 9	3.24E-02	7.15E-03	5.37E-04	Detected
	Mar. 9 – Mar. 23	3.46E-02	6.58E-03	6.42E-04	Detected
	Mar. 23 – Apr. 6	2.78E-02	5.11E-03	2.87E-04	Detected
	Apr. 6 – Apr. 26	3.24E-02	5.77E-03	5.99E-04	Detected
	Apr. 26 – May 9	3.07E-02	5.70E-03	4.55E-04	Detected
	May 9 – May 25	1.81E-02	3.77E-03	4.96E-04	Detected
	May 25 – Jun. 16	2.84E-02	4.80E-03	4.91E-04	Detected
	Jun. 16 – Jul. 8	2.75E-02	4.99E-03	5.66E-04	Detected
	Jul. 8 – Jul. 20	2.98E-02	5.77E-03	7.81E-04	Detected

Table 3-38: Activity density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Carlsbad Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{234}U	Jul. 20 – Jul. 27	4.56E-02	1.02E-02	1.06E-03	Detected
	Jul. 27 - Aug. 23	2.80E-02	4.84E-03	3.52E-04	Detected
	Aug. 23 – Sep. 30	1.90E-02	4.12E-03	6.40E-04	Detected
	Sep. 30 – Oct. 24	2.00E-02	4.19E-03	4.22E-04	Detected
	Oct. 24 – Nov. 29	2.54E-02	4.38E-03	4.15E-04	Detected
	Nov. 29 – Dec. 21	2.92E-02	5.48E-03	7.36E-04	Detected
	Dec. 21 – Jan. 6	3.41E-02	8.78E-03	1.39E-03	Detected
^{235}U	Jan. 8 – Jan. 27	1.02E-03	1.08E-03	9.57E-04	Detected
	Jan. 27 – Feb. 10	6.96E-03	2.42E-03	1.49E-03	Detected
	Feb. 10 – Feb. 24	1.52E-03	9.54E-04	6.01E-04	Detected
	Feb. 24 – Mar. 9	5.36E-03	1.62E-03	1.01E-03	Detected
	Mar. 9 – Mar. 23	1.23E-03	7.71E-04	7.04E-04	Detected
	Mar. 23 – Apr. 6	1.20E-03	6.17E-04	4.56E-04	Detected
	Apr. 6 – Apr. 26	1.10E-03	6.14E-04	5.18E-04	Detected
	Apr. 26 – May 9	1.34E-03	6.61E-04	2.93E-04	Detected
	May 9 – May 25	1.16E-03	5.27E-04	3.45E-04	Detected
	May 25 – Jun. 16	2.00E-03	6.32E-04	3.80E-04	Detected
	Jun. 16 – Jul. 8	1.47E-03	6.37E-04	4.90E-04	Detected
	Jul. 8 – Jul. 20	3.21E-03	9.85E-04	6.51E-04	Detected
	Jul. 20 – Jul. 27	2.57E-03	1.40E-03	9.94E-04	Detected
	Jul. 27 - Aug. 23	1.25E-03	5.31E-04	3.29E-04	Detected
	Aug. 23 – Sep. 30	1.07E-03	6.29E-04	5.44E-04	Detected
	Sep. 30 – Oct. 24	1.10E-03	6.04E-04	5.85E-04	Detected
	Oct. 24 – Nov. 29	1.27E-03	4.91E-04	2.24E-04	Detected
	Nov. 29 – Dec. 21	1.10E-03	6.07E-04	4.84E-04	Detected
	Dec. 21 – Jan. 6	1.69E-03	1.19E-03	7.08E-04	Detected
^{238}U	Jan. 8 – Jan. 27	3.59E-02	8.70E-03	1.30E-03	Detected
	Jan. 27 – Feb. 10	4.22E-02	1.05E-02	2.36E-03	Detected
	Feb. 10 – Feb. 24	4.35E-02	8.42E-03	7.35E-04	Detected
	Feb. 24 – Mar. 9	2.96E-02	6.82E-03	1.16E-03	Detected
	Mar. 9 – Mar. 23	3.51E-02	7.71E-04	7.04E-04	Detected
	Mar. 23 – Apr. 6	2.51E-02	4.81E-03	6.18E-04	Detected
	Apr. 6 – Apr. 26	2.79E-02	5.28E-03	8.61E-04	Detected
	Apr. 26 – May 9	2.86E-02	5.48E-03	7.19E-04	Detected
	May 9 – May 25	1.75E-02	3.71E-03	6.91E-04	Detected
	May 25 – Jun. 16	2.62E-02	4.55E-03	4.09E-04	Detected

Table 3-38: Activity Density of uranium isotopes (^{234}U, ^{235}U and ^{238}U) in the filter samples collected from Carlsbad Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{238}U	Jun. 16 – Jul. 8	2.83E-02	5.08E-03	5.65E-04	Detected
	Jul. 8 – Jul. 20	3.04E-02	5.85E-03	8.43E-04	Detected
	Jul. 20 – Jul. 27	3.85E-02	9.39E-03	1.70E-03	Detected
	Jul. 27 - Aug. 23	2.83E-02	4.87E-03	5.63E-04	Detected
	Aug. 23 – Sep. 30	1.87E-02	1.78E-04	2.48E-04	Detected
	Sep. 30 – Oct. 24	1.95E-02	1.64E-04	3.47E-04	Detected
	Oct. 24 – Nov. 29	2.53E-02	1.44E-04	2.59E-04	Detected
	Nov. 29 – Dec. 21	2.85E-02	5.27E-04	1.45E-03	Detected
	Dec. 21 – Jan. 6	3.86E-02	3.99E-04	8.82E-04	Detected

Table 3-39: Activity concentrations of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Loving Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{137}Cs	Jan. 8 – Jan. 27	5.14E-07	6.08E-07	2.01E-06	Not detected
	Jan. 27 – Feb. 10	-8.57E-07	2.02E-06	6.71E-06	Not detected
	Feb. 10 – Feb. 24	4.46E-07	1.07E-06	3.54E-06	Not detected
	Feb. 24 – Mar. 9	1.78E-06	1.04E-06	3.43E-06	Not detected
	Mar. 9 – Mar. 23	1.96E-07	2.01E-06	6.67E-06	Not detected
	Mar. 23 – Apr. 6	8.50E-07	8.42E-07	2.78E-06	Not detected
	Apr. 6 – Apr. 26	5.79E-08	7.53E-07	2.49E-06	Not detected
	Apr. 26 – May 9	3.58E-08	9.29E-07	3.08E-06	Not detected
	May 9 – May 25	-2.67E-07	9.37E-07	3.11E-06	Not detected
	May 25 – Jun. 16	-4.78E-07	1.35E-06	4.49E-06	Not detected
	Jun. 16 – Jul. 8	8.37E-07	6.96E-07	2.29E-06	Not detected
	Jul. 8 – Jul. 20	1.22E-06	1.56E-06	5.17E-06	Not detected
	Jul. 20 – Jul. 27	-4.24E-07	1.66E-06	5.52E-06	Not detected
	Jul. 27 - Aug. 23	4.65E-07	4.71E-07	1.56E-06	Not detected
	Aug. 23 – Sep. 30	1.29E-07	3.04E-07	1.01E-06	Not detected
	Sep. 30 – Oct. 24	2.25E-07	5.12E-07	1.70E-06	Not detected
	Oct. 24 – Nov. 29	5.07E-08	4.44E-07	1.47E-06	Not detected
	Nov. 29 – Dec. 21	2.00E-07	6.90E-07	2.29E-06	Not detected
	Dec. 21 – Jan. 6	8.84E-07	9.15E-07	3.02E-06	Not detected
^{60}Co	Jan. 8 – Jan. 27	-7.06E-07	6.45E-07	2.16E-06	Not detected
	Jan. 27 – Feb. 10	-1.40E-06	1.96E-06	6.58E-06	Not detected
	Feb. 10 – Feb. 24	1.31E-07	8.64E-07	2.87E-06	Not detected

Table 3-39: Activity concentrations of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Loving Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{60}Co	Feb. 24 – Mar. 9	7.10E-07	8.56E-07	2.83E-06	Not detected
	Mar. 9 – Mar. 23	-2.68E-06	1.96E-06	6.62E-06	Not detected
	Mar. 23 – Apr. 6	-5.20E-07	8.67E-07	2.90E-06	Not detected
	Apr. 6 – Apr. 26	-4.68E-07	6.23E-07	2.08E-06	Not detected
	Apr. 26 – May 9	-5.77E-07	9.26E-07	3.10E-06	Not detected
	May 9 – May 25	6.66E-07	7.45E-07	2.46E-06	Not detected
	May 25 – Jun. 16	-1.77E-07	1.25E-06	4.17E-06	Not detected
	Jun. 16 – Jul. 8	1.65E-07	5.83E-07	1.94E-06	Not detected
	Jul. 8 – Jul. 20	-2.40E-07	1.31E-06	4.38E-06	Not detected
	Jul. 20 – Jul. 27	-1.57E-06	1.73E-06	5.80E-06	Not detected
	Jul. 27 - Aug. 23	-4.07E-07	4.93E-07	1.65E-06	Not detected
	Aug. 23 – Sep. 30	7.51E-08	3.15E-07	1.05E-06	Not detected
	Sep. 30 – Oct. 24	2.35E-07	5.27E-07	1.76E-06	Not detected
	Oct. 24 – Nov. 29	4.02E-07	3.72E-07	1.25E-06	Not detected
	Nov. 29 – Dec. 21	2.11E-07	5.82E-07	1.94E-06	Not detected
	Dec. 21 – Jan. 6	1.34E-06	7.97E-07	2.68E-06	Not detected
^{40}K	Jan. 8 – Jan. 27	3.24E-05	7.74E-06	2.49E-05	Detected
	Jan. 27 – Feb. 10	4.40E-05	1.99E-05	6.50E-05	Not detected
	Feb. 10 – Feb. 24	3.45E-05	1.11E-05	3.56E-05	Not detected
	Feb. 24 – Mar. 9	3.82E-05	1.09E-05	3.46E-05	Detected
	Mar. 9 – Mar. 23	3.95E-05	2.00E-05	6.55E-05	Not detected
	Mar. 23 – Apr. 6	6.62E-05	1.08E-05	3.42E-05	Detected
	Apr. 6 – Apr. 26	4.71E-05	8.00E-06	2.41E-05	Detected
	Apr. 26 – May 9	7.76E-05	1.14E-05	3.60E-05	Detected
	May 9 – May 25	4.23E-05	9.65E-06	3.02E-05	Detected
	May 25 – Jun. 16	5.93E-05	1.30E-05	4.09E-05	Detected
	Jun. 16 – Jul. 8	3.67E-05	7.43E-06	2.30E-05	Detected
	Jul. 8 – Jul. 20	6.82E-05	1.64E-05	5.17E-05	Detected
	Jul. 20 – Jul. 27	8.20E-05	2.07E-05	6.69E-05	Detected
	Jul. 27 - Aug. 23	3.62E-05	5.90E-06	1.87E-05	Detected
	Aug. 23 – Sep. 30	1.55E-05	3.85E-06	1.25E-05	Detected
	Sep. 30 – Oct. 24	4.13E-05	6.37E-06	2.01E-05	Detected
	Oct. 24 – Nov. 29	3.28E-05	4.80E-06	1.41E-05	Detected
	Nov. 29 – Dec. 21	3.88E-05	7.15E-06	2.18E-05	Detected
	Dec. 21 – Jan. 6	3.56E-05	9.51E-06	3.01E-05	Detected

Table 3-40: Activity concentrations of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Carlsbad Station

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{137}Cs	Jan. 8 – Jan. 27	6.07E-07	7.87E-07	2.60E-06	Not detected
	Jan. 27 – Feb. 10	-1.19E-06	1.11E-06	3.58E-06	Not detected
	Feb. 10 – Feb. 24	-5.67E-07	2.01E-06	6.69E-06	Not detected
	Feb. 24 – Mar. 9	-3.17E-07	8.39E-07	2.79E-06	Not detected
	Mar. 9 – Mar. 23	2.82E-06	1.05E-06	3.44E-06	Not detected
	Mar. 23 – Apr. 6	3.56E-07	1.06E-06	3.52E-06	Not detected
	Apr. 6 – Apr. 26	1.16E-06	1.40E-06	4.62E-06	Not detected
	Apr. 26 – May 9	1.05E-06	2.53E-06	7.16E-06	Not detected
	May 9 – May 25	-1.97E-06	1.80E-06	6.00E-06	Not detected
	May 25 – Jun. 16	4.61E-07	1.34E-06	4.45E-06	Not detected
	Jun. 16 – Jul. 8	-9.05E-07	1.41E-06	4.68E-06	Not detected
	Jul. 8 – Jul. 20	1.07E-06	2.47E-06	8.17E-06	Not detected
	Jul. 20 – Jul. 27	1.85E-06	2.12E-06	7.00E-06	Not detected
	Jul. 27 - Aug. 23	8.63E-07	5.79E-07	1.91E-06	Not detected
	Aug. 23 – Sep. 30	9.09E-08	3.92E-07	1.30E-06	Not detected
	Sep. 30 – Oct. 24	1.23E-07	6.19E-07	2.05E-06	Not detected
	Oct. 24 – Nov. 29	2.21E-07	3.31E-07	1.10E-06	Not detected
	Nov. 29 – Dec. 21	2.77E-08	1.32E-07	4.37E-07	Not detected
	Dec. 21 – Jan. 6	4.74E-07	1.75E-06	5.80E-06	Not detected
^{60}Co	Jan. 8 – Jan. 27	-2.48E-07	6.68E-07	2.23E-06	Not detected
	Jan. 27 – Feb. 10	1.19E-07	8.50E-07	2.83E-06	Not detected
	Feb. 10 – Feb. 24	-1.66E-06	1.96E-06	6.57E-06	Not detected
	Feb. 24 – Mar. 9	6.32E-07	8.43E-07	2.79E-06	Not detected
	Mar. 9 – Mar. 23	-6.74E-07	8.81E-07	2.95E-06	Not detected
	Mar. 23 – Apr. 6	-6.74E-07	8.87E-07	2.97E-06	Not detected
	Apr. 6 – Apr. 26	-4.52E-07	1.36E-06	4.55E-06	Not detected
	Apr. 26 – May 9	3.36E-07	9.65E-07	3.20E-06	Not detected
	May 9 – May 25	-4.19E-06	1.76E-06	5.97E-06	Not detected
	May 25 – Jun. 16	-7.09E-07	1.29E-06	4.31E-06	Not detected
	Jun. 16 – Jul. 8	1.17E-06	1.29E-06	4.27E-06	Not detected
	Jul. 8 – Jul. 20	1.82E-06	2.29E-06	7.58E-06	Not detected
	Jul. 20 – Jul. 27	-2.04E-06	1.78E-06	5.98E-06	Not detected
	Jul. 27 - Aug. 23	-5.86E-09	4.92E-07	1.64E-06	Not detected
	Aug. 23 – Sep. 30	2.18E-07	3.23E-07	1.08E-06	Not detected
	Sep. 30 – Oct. 24	4.71E-07	5.14E-07	1.72E-06	Not detected
	Oct. 24 – Nov. 29	1.67E-07	3.27E-07	1.09E-06	Not detected
	Nov. 29 – Dec. 21	1.25E-07	1.22E-07	4.10E-07	Not detected
	Dec. 21 – Jan. 6	2.40E-07	1.69E-06	5.65E-06	Not detected

Table 3-40: Activity concentrations of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Carlsbad Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/m^3	Unc. (2σ) Bq/m^3	MDC Bq/m^3	Status
^{40}K	Jan. 8 – Jan. 27	2.14E-05	8.15E-06	2.63E-05	Not detected
	Jan. 27 – Feb. 10	3.79E-05	1.08E-05	3.44E-05	Detected
	Feb. 10 – Feb. 24	3.26E-05	1.97E-05	6.46E-05	Not detected
	Feb. 24 – Mar. 9	3.17E-05	1.05E-05	3.43E-05	Not detected
	Mar. 9 – Mar. 23	4.04E-05	1.13E-05	3.58E-05	Detected
	Mar. 23 – Apr. 6	5.62E-05	1.13E-05	3.48E-05	Detected
	Apr. 6 – Apr. 26	3.25E-05	1.43E-05	4.66E-05	Not detected
	Apr. 26 – May 9	6.38E-05	1.25E-05	3.84E-05	Detected
	May 9 – May 25	3.02E-05	1.74E-05	5.72E-05	Not detected
	May 25 – Jun. 16	4.27E-05	1.29E-05	4.16E-05	Detected
	Jun. 16 – Jul. 8	3.06E-05	1.40E-05	4.58E-05	Not detected
	Jul. 8 – Jul. 20	8.55E-05	2.29E-05	7.32E-05	Detected
	Jul. 20 – Jul. 27	1.01E-04	2.16E-05	6.72E-05	Detected
	Jul. 27 - Aug. 23	2.62E-05	6.21E-06	1.95E-05	Detected
	Aug. 23 – Sep. 30	1.72E-05	4.05E-06	1.27E-05	Detected
	Sep. 30 – Oct. 24	3.33E-05	6.54E-06	2.02E-05	Detected
	Oct. 24 – Nov. 29	2.58E-05	4.15E-06	1.32E-05	Detected
	Nov. 29 – Dec. 21	4.48E-06	1.28E-06	4.10E-06	Detected
	Dec. 21 – Jan. 6	3.80E-05	1.68E-05	5.48E-05	Not detected

Table 3-41: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Loving Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{137}Cs	Jan. 8 – Jan. 27	1.33E-02	1.58E-02	5.22E-02	Not detected
	Jan. 27 – Feb. 10	-1.95E-02	4.59E-02	1.53E-01	Not detected
	Feb. 10 – Feb. 24	1.03E-02	2.48E-02	8.19E-02	Not detected
	Feb. 24 – Mar. 9	3.95E-02	2.31E-02	7.60E-02	Not detected
	Mar. 9 – Mar. 23	3.42E-03	3.51E-02	1.16E-01	Not detected
	Mar. 23 – Apr. 6	9.51E-03	9.43E-03	3.11E-02	Not detected
	Apr. 6 – Apr. 26	1.06E-03	1.37E-02	4.55E-02	Not detected
	Apr. 26 – May 9	4.68E-04	1.21E-02	4.02E-02	Not detected
	May 9 – May 25	-4.93E-03	1.73E-02	5.75E-02	Not detected
	May 25 – Jun. 16	-8.09E-03	2.29E-02	7.61E-02	Not detected
	Jun. 16 – Jul. 8	1.85E-02	1.54E-02	5.06E-02	Not detected
	Jul. 8 – Jul. 20	2.05E-02	2.63E-02	8.68E-02	Not detected
	Jul. 20 – Jul. 27	-8.90E-03	3.49E-02	1.16E-01	Not detected

Table 3-41: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Loving Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{137}Cs	Jul. 27 - Aug. 23	9.21E-03	9.35E-03	3.09E-02	Not detected
	Aug. 23 – Sep. 30	4.12E-03	9.74E-03	3.22E-02	Not detected
	Sep. 30 – Oct. 24	4.71E-03	1.07E-02	3.56E-02	Not detected
	Oct. 24 – Nov. 29	1.26E-03	1.10E-02	3.65E-02	Not detected
	Nov. 29 – Dec. 21	4.68E-03	1.62E-02	5.36E-02	Not detected
	Dec. 21 – Jan. 6	3.80E-02	3.93E-02	1.30E-01	Not detected
^{60}Co	Jan. 8 – Jan. 27	-1.83E-02	1.67E-02	5.62E-02	Not detected
	Jan. 27 – Feb. 10	-3.19E-02	4.46E-02	1.50E-01	Not detected
	Feb. 10 – Feb. 24	3.04E-03	2.00E-02	6.66E-02	Not detected
	Feb. 24 – Mar. 9	1.57E-02	1.90E-02	6.27E-02	Not detected
	Mar. 9 – Mar. 23	-4.67E-02	3.43E-02	1.15E-01	Not detected
	Mar. 23 – Apr. 6	-5.82E-03	9.71E-03	3.25E-02	Not detected
	Apr. 6 – Apr. 26	-8.53E-03	1.14E-02	3.80E-02	Not detected
	Apr. 26 – May 9	-7.53E-03	1.21E-02	4.05E-02	Not detected
	May 9 – May 25	1.23E-02	1.38E-02	4.55E-02	Not detected
	May 25 – Jun. 16	-3.00E-03	2.12E-02	7.07E-02	Not detected
	Jun. 16 – Jul. 8	3.65E-03	1.29E-02	4.28E-02	Not detected
	Jul. 8 – Jul. 20	-4.04E-03	2.21E-02	7.36E-02	Not detected
	Jul. 20 – Jul. 27	-3.29E-02	3.64E-02	1.22E-01	Not detected
	Jul. 27 - Aug. 23	-8.06E-03	9.78E-03	3.28E-02	Not detected
	Aug. 23 – Sep. 30	2.40E-03	1.01E-02	3.35E-02	Not detected
	Sep. 30 – Oct. 24	4.91E-03	1.10E-02	3.69E-02	Not detected
	Oct. 24 – Nov. 29	9.98E-03	9.23E-03	3.09E-02	Not detected
	Nov. 29 – Dec. 21	4.94E-03	1.36E-02	4.54E-02	Not detected
	Dec. 21 – Jan. 6	5.75E-02	3.42E-02	1.15E-01	Not detected
^{40}K	Jan. 8 – Jan. 27	8.41E-01	2.01E-01	6.48E-01	Detected
	Jan. 27 – Feb. 10	1.00E+00	4.53E-01	1.48E+00	Not detected
	Feb. 10 – Feb. 24	7.98E-01	2.57E-01	8.26E-01	Not detected
	Feb. 24 – Mar. 9	8.46E-01	2.41E-01	7.67E-01	Detected
	Mar. 9 – Mar. 23	6.89E-01	3.49E-01	1.14E+00	Not detected
	Mar. 23 – Apr. 6	7.41E-01	1.21E-01	3.83E-01	Detected
	Apr. 6 – Apr. 26	8.58E-01	1.46E-01	4.40E-01	Detected
	Apr. 26 – May 9	1.01E+00	1.49E-01	4.71E-01	Detected
	May 9 – May 25	7.82E-01	1.78E-01	5.58E-01	Detected
	May 25 – Jun. 16	1.01E+00	2.19E-01	6.92E-01	Detected
	Jun. 16 – Jul. 8	8.10E-01	1.64E-01	5.08E-01	Detected

Table 3-41: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Loving Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{40}K	Jul. 8 – Jul. 20	1.15E+00	2.76E-01	8.69E-01	Detected
	Jul. 20 – Jul. 27	1.72E+00	4.35E-01	1.41E+00	Detected
	Jul. 27 - Aug. 23	7.17E-01	1.17E-01	3.71E-01	Detected
	Aug. 23 – Sep. 30	4.95E-01	1.23E-01	3.99E-01	Detected
	Sep. 30 – Oct. 24	8.64E-01	1.33E-01	4.22E-01	Detected
	Oct. 24 – Nov. 29	8.13E-01	1.19E-01	3.49E-01	Detected
	Nov. 29 – Dec. 21	9.08E-01	1.67E-01	5.11E-01	Detected
	Dec. 21 – Jan. 6	1.53E+00	4.08E-01	1.29E+00	Detected

Table 3-42: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Carlsbad Station

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{137}Cs	Jan. 8 – Jan. 27	3.53E-02	4.57E-02	1.51E-01	Not detected
	Jan. 27 – Feb. 10	-5.44E-02	5.09E-02	1.64E-01	Not detected
	Feb. 10 – Feb. 24	-1.77E-02	6.29E-02	2.09E-01	Not detected
	Feb. 24 – Mar. 9	-9.15E-03	2.42E-02	8.03E-02	Not detected
	Mar. 9 – Mar. 23	6.71E-02	2.51E-02	8.18E-02	Not detected
	Mar. 23 – Apr. 6	7.15E-03	2.14E-02	7.09E-02	Not detected
	Apr. 6 – Apr. 26	3.23E-02	3.91E-02	1.29E-01	Not detected
	Apr. 26 – May 9	1.99E-02	4.82E-02	1.36E-01	Not detected
	May 9 – May 25	-3.64E-02	3.32E-02	1.11E-01	Not detected
	May 25 – Jun. 16	1.07E-02	3.12E-02	1.03E-01	Not detected
	Jun. 16 – Jul. 8	-2.24E-02	3.48E-02	1.16E-01	Not detected
	Jul. 8 – Jul. 20	1.99E-02	4.59E-02	1.52E-01	Not detected
	Jul. 20 – Jul. 27	4.39E-02	5.04E-02	1.66E-01	Not detected
	Jul. 27 - Aug. 23	2.59E-02	1.74E-02	5.71E-02	Not detected
	Aug. 23 – Sep. 30	3.75E-03	1.62E-02	5.37E-02	Not detected
	Sep. 30 – Oct. 24	3.55E-03	1.78E-02	5.89E-02	Not detected
	Oct. 24 – Nov. 29	8.61E-03	1.29E-02	4.29E-02	Not detected
	Nov. 29 – Dec. 21	9.01E-03	4.28E-02	1.42E-01	Not detected
	Dec. 21 – Jan. 6	2.57E-02	9.47E-02	3.14E-01	Not detected
^{60}Co	Jan. 8 – Jan. 27	-1.44E-02	3.88E-02	1.30E-01	Not detected
	Jan. 27 – Feb. 10	5.43E-03	3.88E-02	1.29E-01	Not detected
	Feb. 10 – Feb. 24	-5.20E-02	6.12E-02	2.05E-01	Not detected
	Feb. 24 – Mar. 9	1.82E-02	2.43E-02	8.04E-02	Not detected

Table 3-42: Activity density of gamma emitting isotopes (^{137}Cs, ^{60}Co and ^{40}K) in the filter samples collected from Carlsbad Station (continued)

Radionuclides	Sample Date 2016	Activity Bq/g	Unc. (2σ) Bq/g	MDC Bq/g	Status
^{60}Co	Mar. 9 – Mar. 23	-1.60E-02	2.10E-02	7.01E-02	Not detected
	Mar. 23 – Apr. 6	-1.36E-02	1.79E-02	5.97E-02	Not detected
	Apr. 6 – Apr. 26	-1.26E-02	3.81E-02	1.27E-01	Not detected
	Apr. 26 – May 9	6.40E-03	1.84E-02	6.10E-02	Not detected
	May 9 – May 25	-7.72E-02	3.24E-02	1.10E-01	Not detected
	May 25 – Jun. 16	-1.65E-02	2.99E-02	1.00E-01	Not detected
	Jun. 16 – Jul. 8	2.90E-02	3.19E-02	1.06E-01	Not detected
	Jul. 8 – Jul. 20	3.39E-02	4.25E-02	1.41E-01	Not detected
	Jul. 20 – Jul. 27	-4.84E-02	4.23E-02	1.42E-01	Not detected
	Jul. 27 - Aug. 23	-1.76E-04	1.47E-02	4.91E-02	Not detected
	Aug. 23 – Sep. 30	8.98E-03	1.33E-02	4.46E-02	Not detected
	Sep. 30 – Oct. 24	1.35E-02	1.48E-02	4.94E-02	Not detected
	Oct. 24 – Nov. 29	6.50E-03	1.27E-02	4.22E-02	Not detected
	Nov. 29 – Dec. 21	4.06E-02	3.96E-02	1.33E-01	Not detected
	Dec. 21 – Jan. 6	1.30E-02	9.15E-02	3.06E-01	Not detected
^{40}K	Jan. 8 – Jan. 27	1.24E+00	4.74E-01	1.53E+00	Not detected
	Jan. 27 – Feb. 10	1.73E+00	4.94E-01	1.57E+00	Detected
	Feb. 10 – Feb. 24	1.02E+00	6.15E-01	2.02E+00	Not detected
	Feb. 24 – Mar. 9	9.15E-01	3.04E-01	9.88E-01	Not detected
	Mar. 9 – Mar. 23	9.60E-01	2.68E-01	8.52E-01	Detected
	Mar. 23 – Apr. 6	1.13E+00	2.27E-01	7.00E-01	Detected
	Apr. 6 – Apr. 26	9.11E-01	4.00E-01	1.30E+00	Not detected
	Apr. 26 – May 9	1.22E+00	2.38E-01	7.32E-01	Detected
	May 9 – May 25	5.57E-01	3.21E-01	1.05E+00	Not detected
	May 25 – Jun. 16	9.92E-01	3.00E-01	9.65E-01	Detected
	Jun. 16 – Jul. 8	7.56E-01	3.47E-01	1.13E+00	Not detected
	Jul. 8 – Jul. 20	1.59E+00	4.26E-01	1.36E+00	Detected
	Jul. 20 – Jul. 27	2.39E+00	5.12E-01	1.59E+00	Detected
	Jul. 27 - Aug. 23	7.85E-01	1.86E-01	5.85E-01	Detected
	Aug. 23 – Sep. 30	7.10E-01	1.67E-01	5.26E-01	Detected
	Sep. 30 – Oct. 24	9.57E-01	1.88E-01	5.79E-01	Detected
	Oct. 24 – Nov. 29	1.00E+00	1.61E-01	5.12E-01	Detected
	Nov. 29 – Dec. 21	1.45E+00	4.17E-01	1.33E+00	Detected
	Dec. 21 – Jan. 6	2.06E+00	9.10E-01	2.97E+00	Not detected

CHAPTER 4

Soil Monitoring

Soil is weathered material, mainly composed of disintegrated rock and organic material that sustains growing plants. Soil can contain pollutants originally released directly to the ground, to the air, or through liquid effluents. The U.S. Department of Energy's (DOE) guidance for environmental monitoring states that soil should be sampled to determine if there is a measurable long-term build-up of radionuclides in the terrestrial environment and to estimate environmental radionuclide inventories (U.S. DOE 1991).

Soil monitoring is of high interest to the CEMRC environmental monitoring program because aerosol releases of contaminants from within the repository could eventually be deposited into surface soils, which then can serve as a source for continuing contaminant exposure and uptake via direct contact, food chain pathways, and re-suspension. Additionally, a soil monitoring program also offers the most direct means of determining the concentrations (activities), distribution, and long-term trends of radionuclides and chemicals present around nuclear facilities. From these perspectives, soil is an integrating medium of primary concern in predictive ecosystem and contaminant transport modeling that requires good information about the dispersion of analytes of concern across the landscape. The source of transuranic radionuclides in soil surrounding the WIPP are almost certainly derived from global fallout from the testing of above-ground nuclear devices, such as ^{238}Pu injected into the stratosphere by the burn-up of a failed radioactive thermal generator in 1964 (Krey, 1967), a release at the Gnome Site located near the WIPP facility, and the regional fallout from the above-ground testing at the Nevada Test Site (NTS) or Nevada National Security Site (NNSS) as it is known today. Each of these sources has characteristic radionuclide signatures and/or abundances that can, in principle, be used to identify their presence in the soils and to estimate their concentrations. In order to determine if such a signature exists for the WIPP, routine soil sampling occurs at locations near the WIPP site.

The WIPP site is situated on the northern margin region of the Chihuahuan desert. The soils of the area are primarily characterized by sand with some areas of gravelly loams, sandy loams and loamy sands (Wilson, 1974; King and Jones, 1971). Caliche underlies much of the area. The topography is generally monotonous with some areas having dune formations. Hummocks are frequently associated with the shrubs that occur throughout the region. Given the lack of topographical relief across the regions and the obvious meter-scale variability due to dunes and hummocks, we postulate that small-scale environmental factors would be as important as contributors to total variability in soil contaminant concentration as would differences between locations separated by kilometers. Several mechanisms have been postulated to explain meter-scale variability in soil activity within arid environments. Small-scale redistribution of

radionuclide contaminated soil particles from vegetation interspaces to vegetated mounds was observed in the desert environment of Nevada Test Site (Romney et al., 1987).

Since 1998, surface soil sampling near the WIPP site has been part of a continuing CEMRC monitoring program designed to measure any changes in environmental levels of radioactivity and to evaluate any increase in radioactivity that might have resulted from WIPP operations. These samples have been analyzed for transuranic actinides and gamma-emitting radionuclides. Following the underground radiological event at the WIPP on February 14, 2014, several soil samples were collected from within a 10-mile radius of the WIPP to assess the regional impact of the February 14 underground radiation release event to the local environment, if any. The measured data show, as expected, that no detectable increases above those typical of previously measured natural variation occurred as a result of the February 14, 2014 underground radiation event.

Results reported herein are from soil samples collected during 2016 from the Near Field grid.

Sample Collection

In 2016, a total of 18 soil samples were collected from the two locations where the high-volume air samplers are stationed around the WIPP site: Site 107 (Near Field) and Site 109 (Cactus Flats). Soil samples at the depth of (0-2 cm) were collected at random short distances and orientations from both locations. The sampling location of soil is shown in Figure 4-1. Individual sampling sites were selected on the basis of relatively flat topography, minimum surface erosion, and minimum surface disturbance by human or livestock activity. Approximately 4L of soil were collected from within a 50×50 cm area for radionuclide analyses. As shown in Figure 4-2, soil samples were excavated using a trowel and placed in plastic bags for transport and storage. Sampling equipment was cleaned and surveyed for radiological contamination between samples. Samples were sieved through a 1 mm mesh screen to remove rocks, roots, and other large material. The soil samples were then ground with a ball mill and homogenized by mixing.

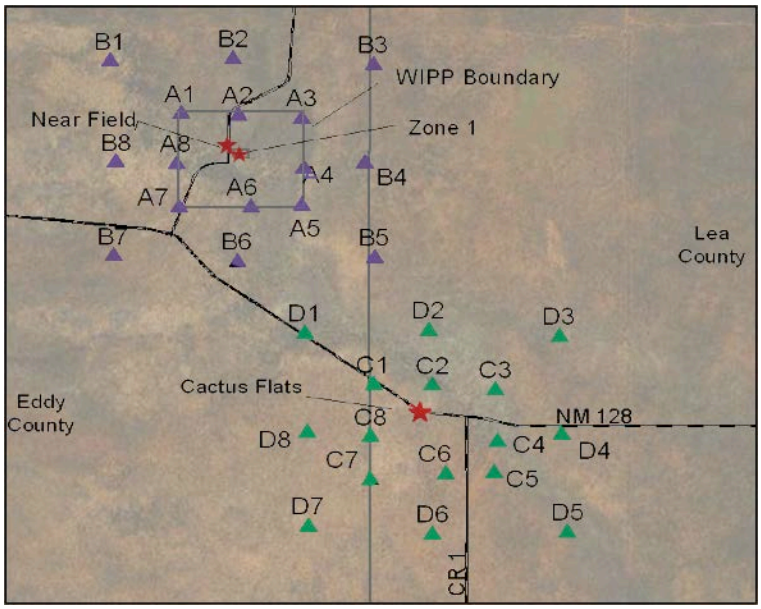


Figure 4-1: Soil Sampling locations in the vicinity of the WIPP Site

Figure 4-2: Soil Sampling in the vicinity of the WIPP site by CEMRC Personnel

Sample Preparation

Soil samples were dried at 110°C and blended prior to sampling. For actinides analyses, 10g of sample were heated in a muffle furnace at 500°C for at least 6 hours to combust organic material. Each sample was then spiked with a radioactive trace and digested in a Teflon beaker with 30 ml of HCl, 10 ml of HNO_3 and 40 ml of HF. Sea sand was used as a matrix for Laboratory Control Standard (LCS) and reagent blank. The samples were heated at 250°C for at least 2 hours; longer heating does no harm. After digestion was completed, the samples were evaporated to dryness and 40 ml of $HClO_4$ was added and evaporated to complete dryness. This step was

repeated once more with 30 ml of $HClO_4$. Then 20 ml of HF was added and evaporated to dryness. To each beaker 80 ml of 8M HNO_3, 1.5 g of H_3BO_3 and 0.5 ml of 30% H_2O_2 were added, covered with a watch glass and heated to boiling for 30 minutes. After cooling, samples were transferred to a 50 ml centrifuge tube and centrifuged at 3600 rpm for 10 minutes. The leachate was filtered through a 0.45 micron filter and transferred to a 250 ml beaker.

Determination of Individual Radionuclides

The oxidation state of Pu was adjusted by adding 1 ml of 1.0M NH_4I with a 10 min wait step, followed by 2 ml of $NaNO_2$. The sample solutions were then ready for the purification procedure with anion exchange and by extraction chromatography. Next Pu was separated from Am and U using an anion exchange column. U was separated from Am on TRU and the Am subsequently purified from lanthanides with TEVA as shown in Figure 4-3. Finally, Pu, Am and U were micro co-precipitated on stainless steel discs for alpha spectrometry (Canberra) and counted for five days as per CEMRC's standard counting protocol.

The samples for gamma analysis were sealed in a 300-mL paint-can and stored for a few days to allow radon progeny to reach equilibrium with parent radionuclides before counting. Dried and sieved soil samples were counted for 48 hours in a high purity germanium detector, HpGe (Canberra).

Data Reporting

The activities of the actinides and gamma radionuclides in the soil samples are reported as activity concentration in Bq/kg. The Activity concentration is calculated as the activity of radionuclides detected in Becquerel (Bq) divided by the weight of the soil in kilograms (kg).

Results and Discussion

The ^{238}Pu, $^{239+240}Pu$, ^{241}Am, isotopes of uranium, and gamma radionuclides ^{40}K, ^{137}Cs and ^{60}Co were analyzed for all the soil samples. The individual concentrations of ^{241}Am, $^{239+240}Pu$ and ^{238}Pu in the soil samples collected from the Near Field are presented in Table 4-1. The $^{239+240}Pu$ concentrations in the Near Field ranged from 0.02 to 0.15 Bq/kg, with a mean value of 0.09 Bq/kg, while that for ^{241}Am ranged from 0.03 to 0.10 Bq/kg, with a mean value of 0.06 Bq/kg. The ^{238}Pu was not detected in any of the soil samples collected in 2016. All detected concentration of $^{239+240}Pu$ and ^{241}Am were extremely low and were relatively close to the respective MDCs. The concentrations of these nuclides are comparable to our historical data recorded for these areas prior to the arrival of TRU wastes in the WIPP and are typical of "background soil". Historical plots of $^{239+240}Pu$, ^{238}Pu, and ^{241}Am concentrations in soil in the vicinity of the WIPP site are shown in Figures 4-4 to 4-6.

The range of $^{239+240}$Pu concentrations (0.032-0.28 Bq/kg) fell within the range reported by Kenney et al., 1995 at the WIPP site (0-0.74 Bq/kg). These values are lower than those measured at Hueston Woods and Urbana, Ohio (0.7-1.0 Bq/kg) (Alberts et al., 1980) and between Ft. Collins and Colorado Springs, Colorado (0.6-1.7 Bq/kg) (Hodge et al., 1996). These results demonstrate that significant variability in background levels of soil contaminants and constituents can occur in areas having relatively low variability in soil texture. The high correlations of the radionuclides and many of the non-radioactive metals to the percentages of silt and clay in the soil explain much of the between-sample variability. The background concentrations of ^{137}Cs, $^{239+240}$Pu and ^{241}Am (Bq/kg) in surface soil around the WIPP site are summarized in Table 4-2.

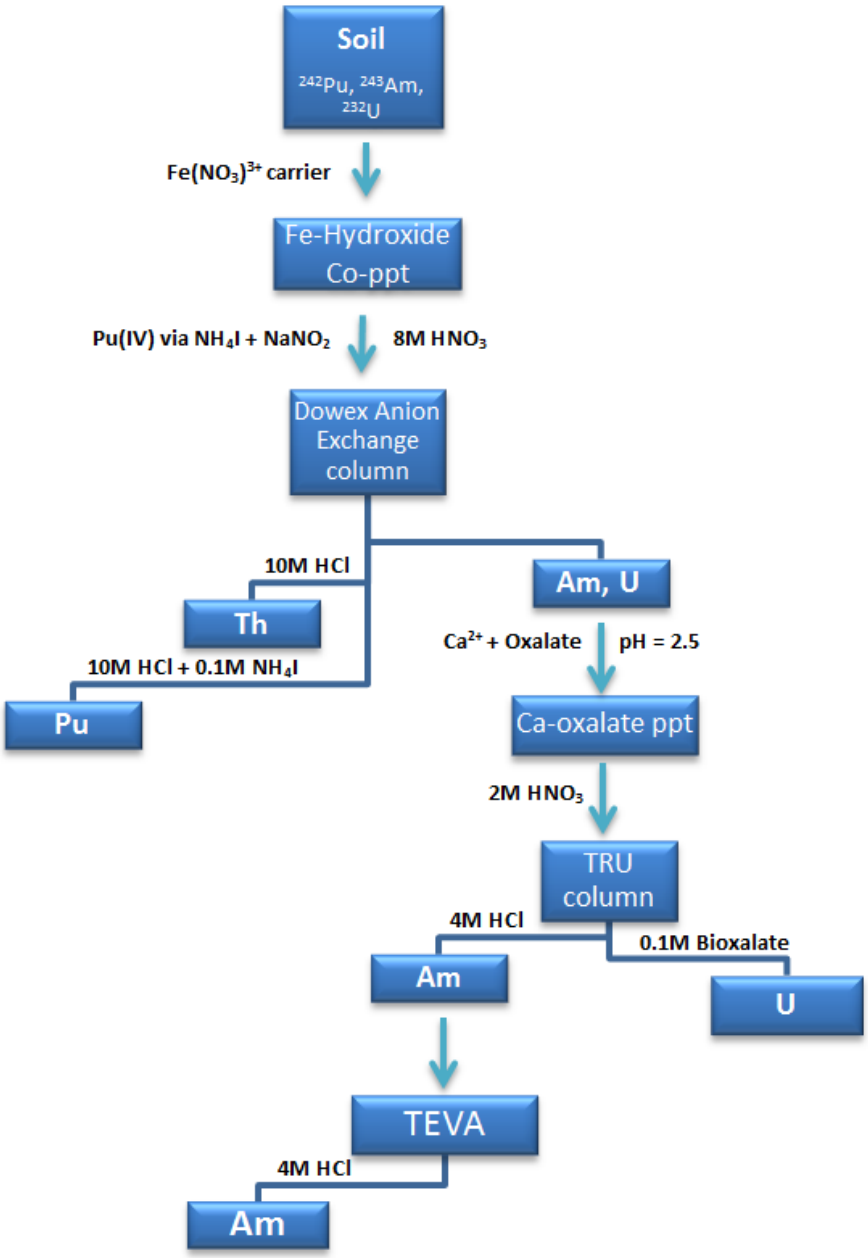


Figure 4-3: Radiochemical separation of Soil Samples

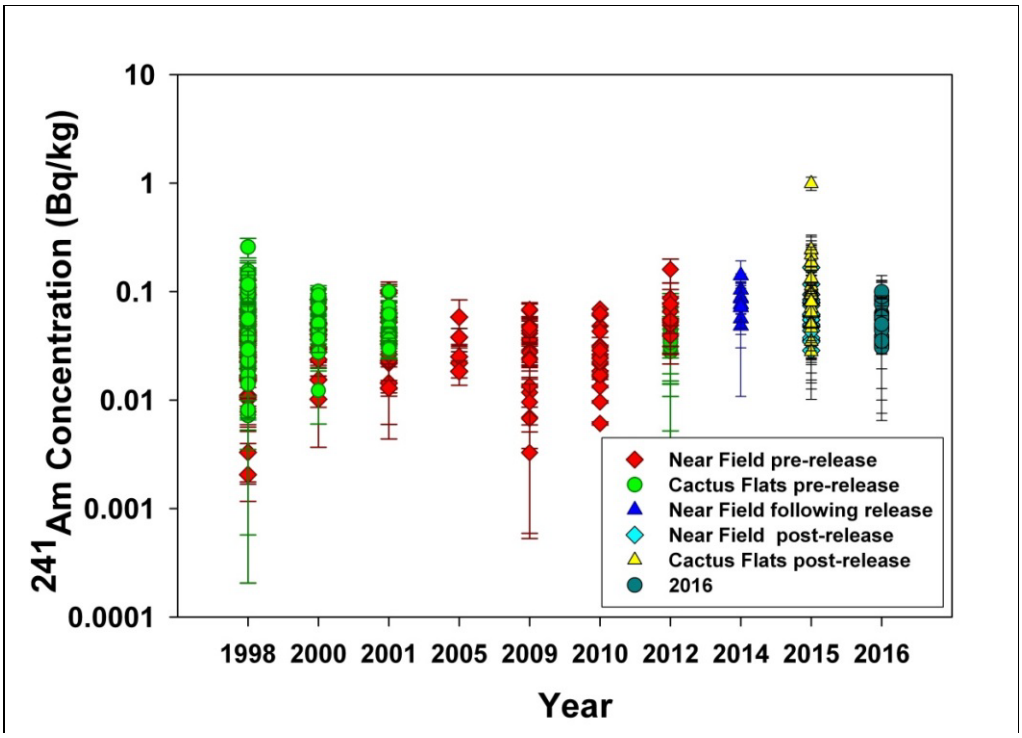


Figure 4-4: The Pre- and Post-radiological event soil concentrations of ^{241}Am in the vicinity of the WIPP site

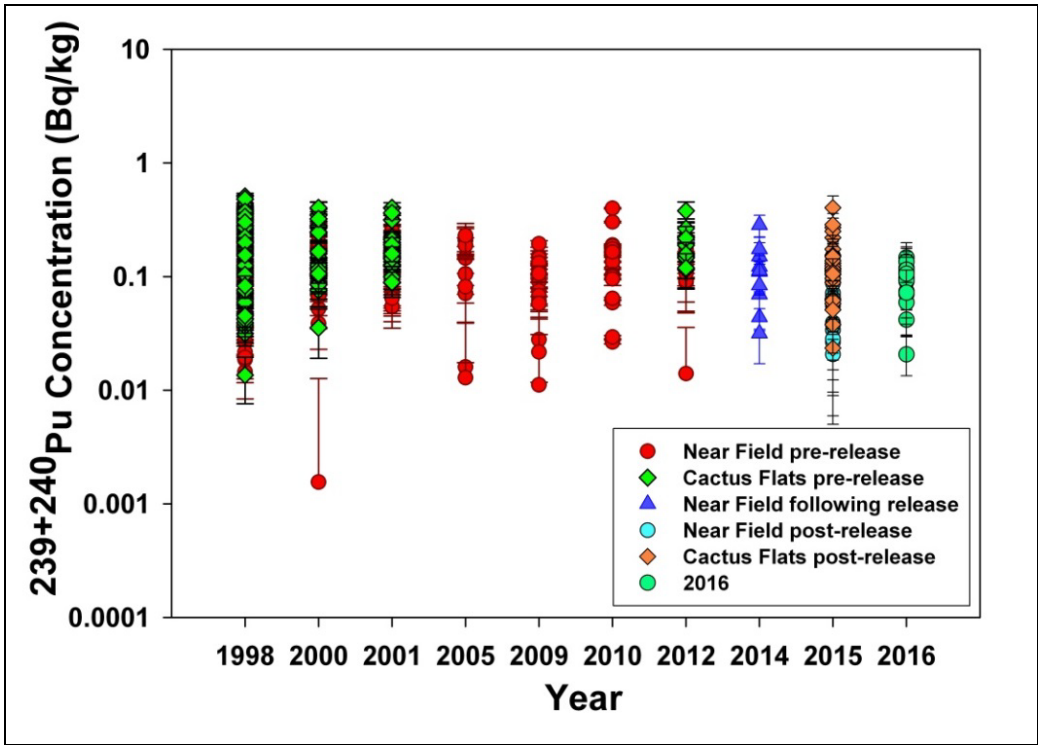


Figure 4-5: The Pre- and Post-radiological event soil concentrations of $^{239+240}$Pu in the vicinity of the WIPP site

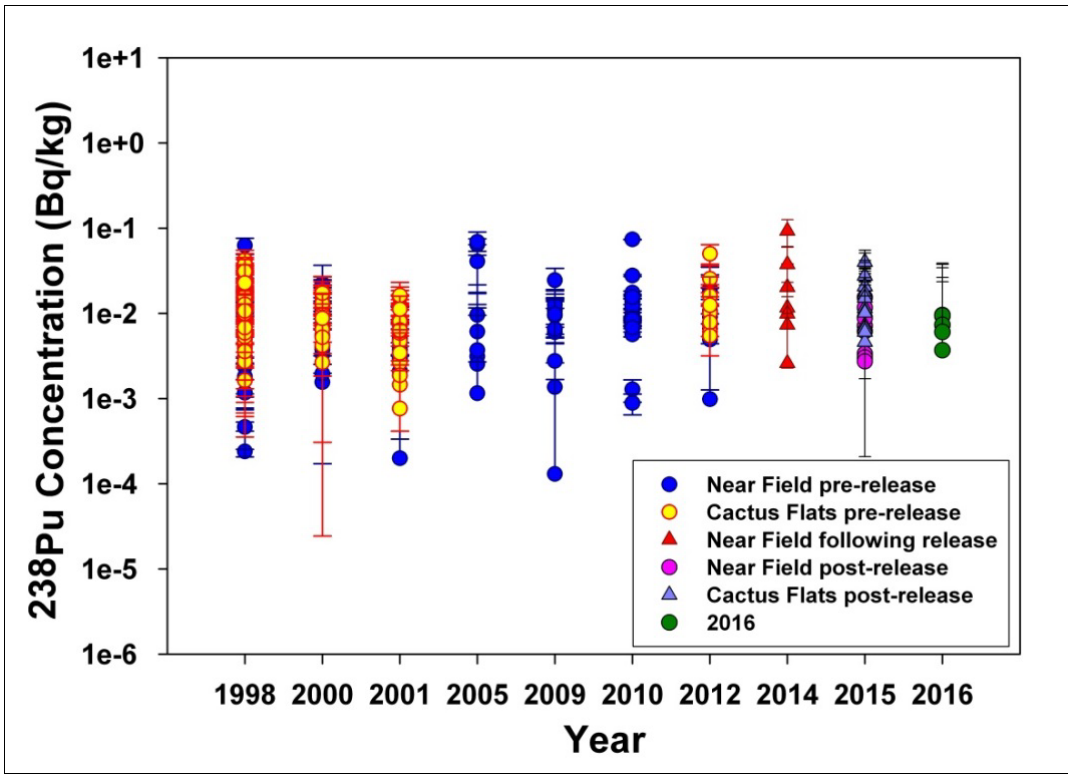


Figure 4-6: The Pre- and post-radiological event soil concentrations of ^{238}Pu in the vicinity of the WIPP site

Concentrations of uranium Isotopes in the WIPP soil

The naturally occurring isotopes of U were detected in all soil samples collected in 2016. Table 4-3 presents the uranium isotope analysis data for the soil samples collected from Near Field in 2016. The highest concentrations of ^{234}U and ^{238}U detected in Near Field soil were 7.84 Bq/kg and 7.66 Bq/kg, respectively, which is consistent with the value measured in 2015 (8.13 Bq/kg for ^{234}U and 7.89 Bq/kg for ^{238}U). The concentration of uranium in soil varies widely, but typically contains about 3 parts per million (ppm), or about 0.074 (Bq/g) picocuries per gram (pCi/g). A square mile of earth, one foot deep, will typically contain over a ton of uranium. The average background concentration of uranium in surface soil is about 2 mg/kg (NCRP 1984). Figure 4-7 illustrates the soil uranium concentration levels in the United States. The concentrations of uranium isotopes measured in soil samples following the February 14, 2014 underground radiation release event were within the range of the baseline phase data for the soil samples collected in 1998 (Figures 4-8 and 4-9) and showed no detectable increases above those typical of previously measured natural variation. The calculated ^{234}U/^{238}U activity ratio in the vicinity of WIPP soil varied between 0.87 to 1.11 with an average value of 0.97±0.06 for the Near Field soils, which is consistent with the average ratios of 0.98±0.04 measured in the soil from the Near Field grid in 2016 and are indicative of the presence of natural uranium . The Figure 4-10 shows the variation in ^{234}U/^{238}U ratio in the soil samples collected from the Near Field grid during 2015-2016. The ^{234}U/^{238}U activity ratio obtained indicated that these two uranium isotopes are in

the state of secular radioactive equilibrium. When soil samples are analyzed using alpha spectrometry the expected secular equilibrium between ^{238}U and ^{234}U is typically observed, but the expected ratio of ^{238}U and ^{235}U is seldom found. In practice it is more common for the ^{238}U to ^{235}U ratio to be lower than expected. This indicates that either there is more ^{235}U present in the sample than is true for natural uranium or there is high bias in the ^{235}U measurement.

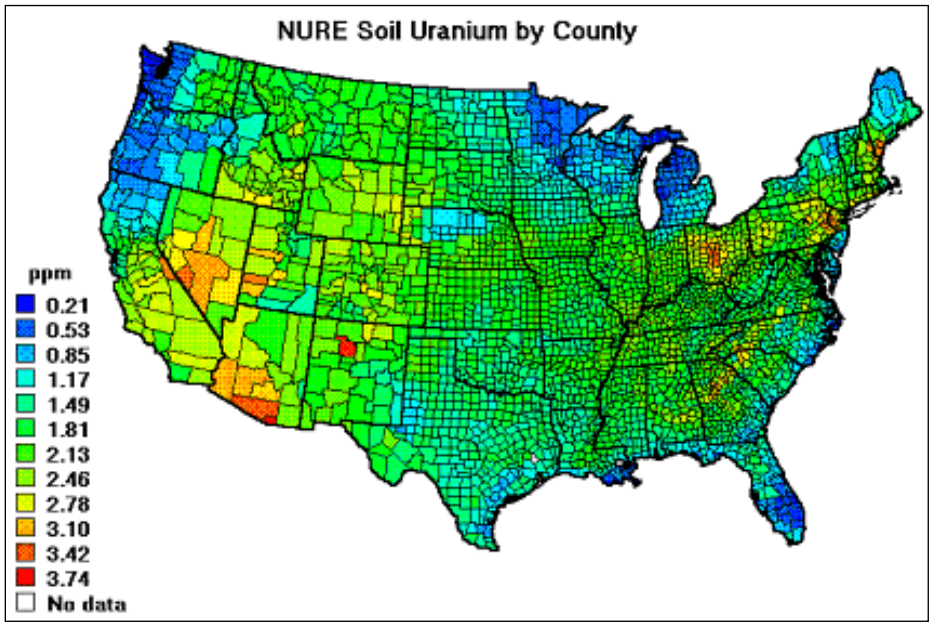


Figure 4-7: Soil uranium concentration levels in the United States
Courtesy: USGS.gov

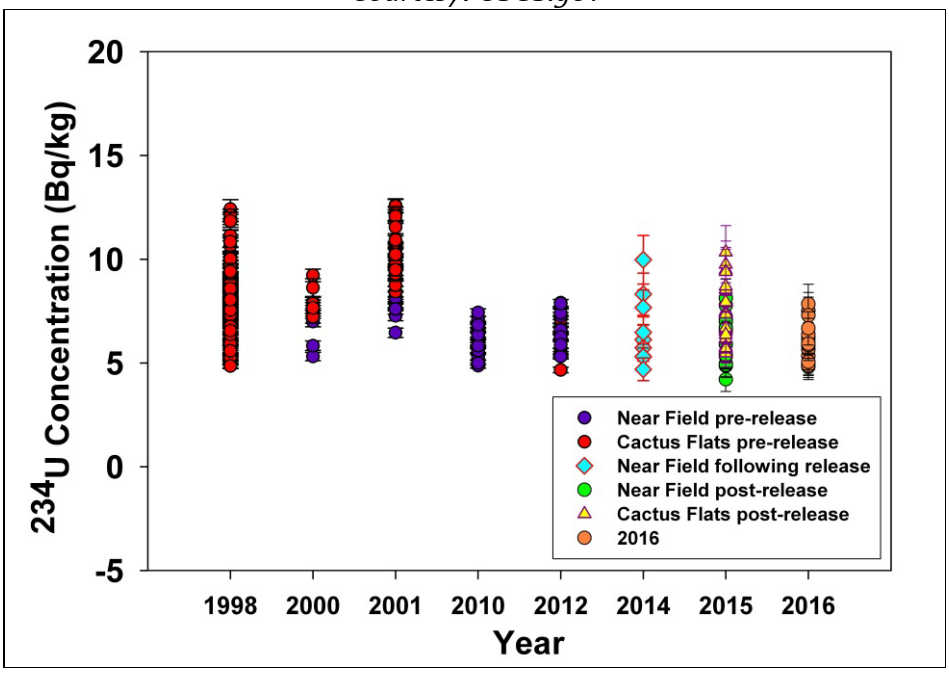


Figure 4-8: The Pre- and post-radiological event soil concentrations of ^{234}U in the vicinity of the WIPP site

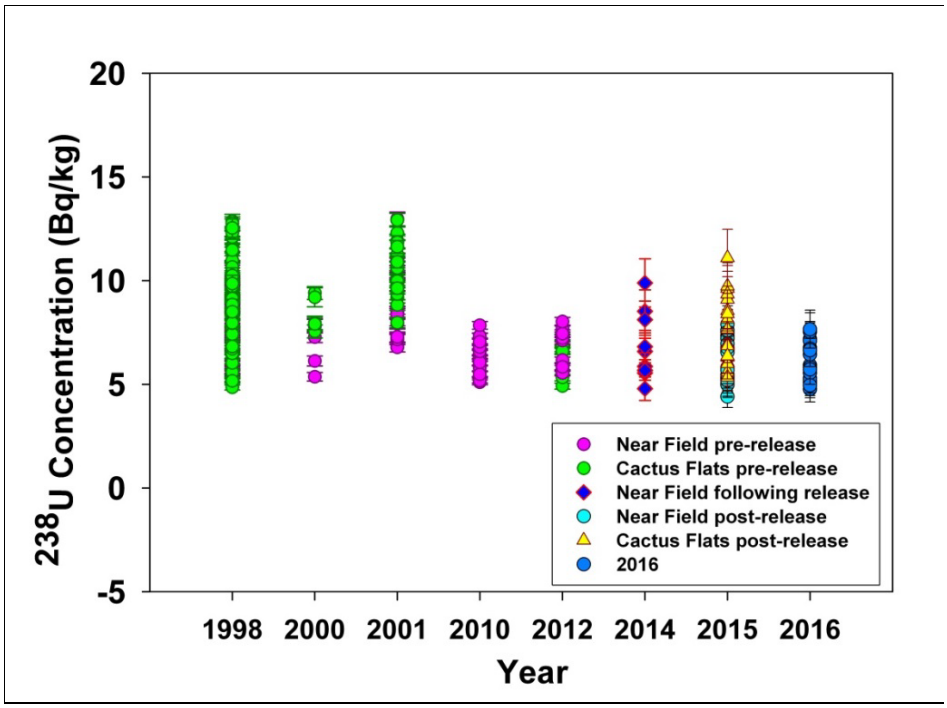


Figure 4-9: The Pre- and post-radiologcial event soil concentrations of ^{238}U in the vicinity of the WIPP site

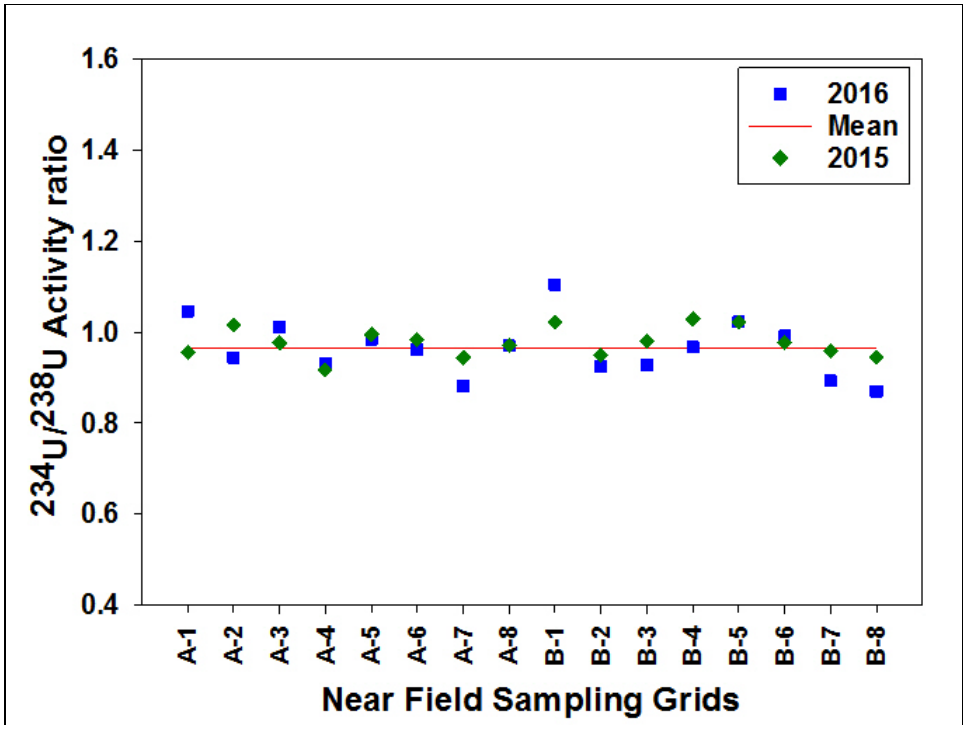


Figure 4-10: The $^{234}U/^{238}U$ activity ratio in the soil samples collected from Near Field grid during 2015- 2016

Concentrations of Gamma Radionuclides in the WIPP soil

The ^{137}Cs was detected in all soil samples Table 4-4. The activity concentration of ^{137}Cs in the Near Field surface soil ranged from 0.25 to 2.91 Bq/kg, with a mean value of 1.40 Bq/kg, while the activity concentration of ^{137}Cs in the Cactus Flats soil ranged from 0.27 to 5.84 Bq/kg, with a mean value of 2.22 Bq/kg. Variability among the ^{137}Cs concentrations was not very significant. Although ^{137}Cs is a fission product, it is ubiquitous in soils because of global fallout from atmospheric weapons testing (Beck and Bennett, 2002 and UNSCEAR, 2000). Like, ^{137}Cs, the ^{40}K was detected in every sample (Table 4-4). This naturally occurring gamma-emitting radionuclide is ubiquitous in soils. The concentrations of ^{40}K fell within the range of values previously measured for the WIPP soil samples. There was no significant difference between concentrations of ^{137}Cs and ^{40}K among sampling locations and the values fell within the range of concentrations previously observed in WIPP soils. The ^{60}Co was not detected at any sampling locations. Historical plots of ^{40}K and ^{137}Cs concentrations in soil in the vicinity of the WIPP site are shown in Figures 4-11 and 4-12. The concentrations have remained relatively constant over the past 10+ years and generally are indicative of worldwide fallout. Some degree of variability is always associated with collecting and analyzing environmental samples; therefore, variations in sample concentrations from year to year are expected.

The concentration of ^{137}Cs in the surface soil at Cactus Flats is approximately 2 times higher than that of surface soil at Near Field, while concentrations of $^{239+240}$Pu and ^{241}Am are approximately 2-3 times higher. However, there is no apparent difference between the radionuclides concentration in soil collected before and after WIPP started receiving TRU waste. The Cactus Flats soil radionuclide concentrations are higher than those measured in the soil samples collected following the radiological event at the WIPP.

One finding presented in the CEMRC 2000 Report was that there were significant differences in many analyte concentrations between the Near Field and Cactus Flats grids. In a subsequent publication differences in soil texture were identified as a likely cause for these observations (Kirchner et al., 2002).

Additionally, the Gnome Site lies approximately 9 km southwest of the WIPP Site and was contaminated with actinide and fission products in 1961 when an underground detonation of a 3-kiloton ^{239}Pu device vented to the atmosphere. The concentrations of $^{239+240}$Pu, ^{238}Pu, and ^{241}Am in Gnome soil were in the range 0.073-1550 Bq/kg, 0.016-219 Bq/kg and 0.043-346 Bq/kg, respectively with an overall mean of 149.0 Bq/kg, 28.8 Bq/kg and 36.1 Bq/kg, respectively (CEMRC Annual Report, 2005/2006). In addition, the WIPP ^{137}Cs concentration in the surface soil was significantly lower than the Gnome soil (CEMRC Annual Report, 2005/2006). The maximum concentration of ^{137}Cs for the Gnome samples, 2890 Bq/kg, was more than 100 times larger than the largest concentration (5.84 Bq/kg) seen in the WIPP surface soil samples in 2016. The monitoring results indicate that there is no evidence of increase in soil radionuclide

concentrations that can be attributed to the recent underground radiological release event at the WIPP.

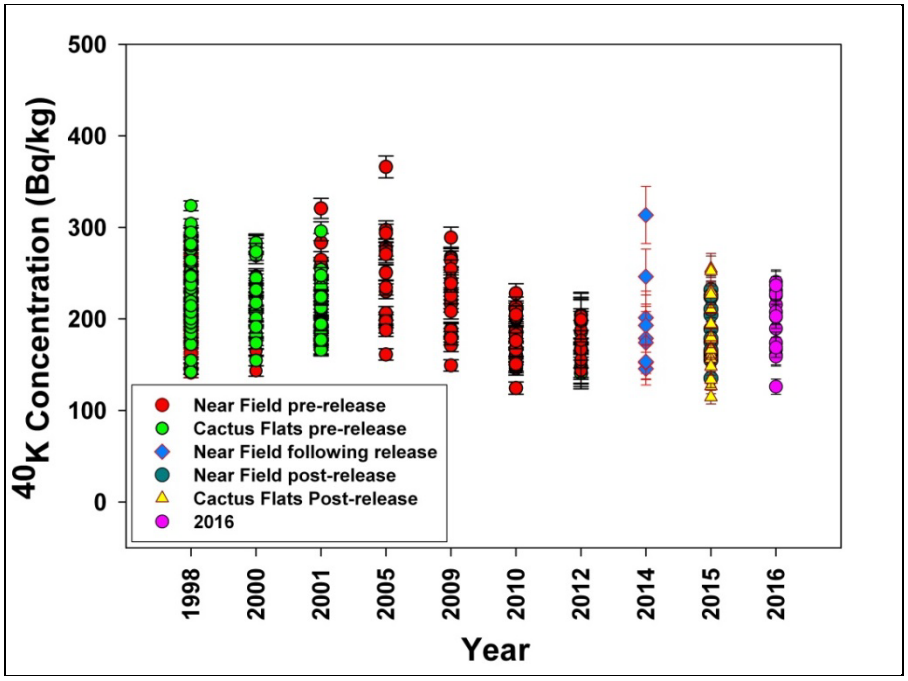


Figure 4-11: The Pre- and Post-radiological event soil concentrations of ^{40}K in the vicinity of the WIPP site

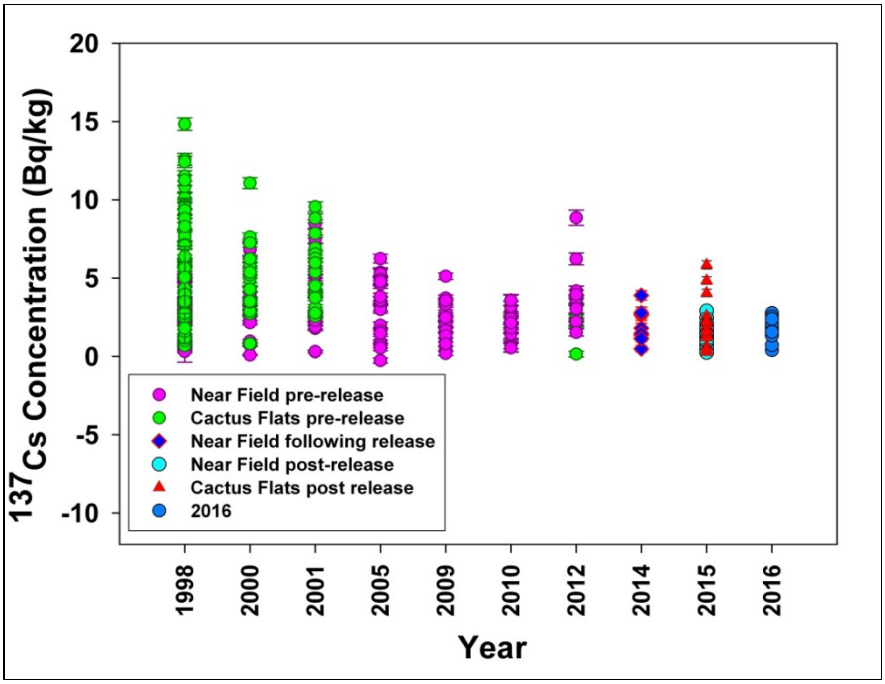


Figure 4-12: The Pre- and Post-radiological event soil concentrations of ^{137}Cs in the vicinity of the WIPP site

Table 4-1: Activity concentrations of ^{241}Am, $^{239+240}Pu$ and ^{238}Pu (Bq/kg) in soil samples collected from Near Field in 2016

Radionuclides	Location	Grid Nodes	Sampling Date	Activity Bq/kg	Unc. (2σ) Bq/kg	MDC Bq/kg	Status
^{241}Am	Near field	A-1	3/22/2016	3.27E-02	2.63E-02	5.06E-02	Not detected
	Near field	A-2	3/22/2016	3.06E-02	3.68E-02	8.07E-02	Not detected
	Near field	A-3	3/22/2016	3.78E-02	3.88E-02	8.06E-02	Not detected
	Near field	A-3 DUP	3/22/2016	6.30E-02	3.61E-02	6.04E-02	Detected
	Near field	A-4	3/22/2016	8.39E-02	3.83E-02	5.45E-02	Detected
	Near field	A-5	3/22/2016	7.67E-02	3.23E-02	4.39E-02	Detected
	Near field	A-6	3/22/2016	4.81E-02	7.88E-02	1.80E-01	Not detected
	Near field	A-7	3/22/2016	5.99E-02	6.14E-02	1.27E-01	Not detected
	Near field	A-8	3/22/2016	8.97E-02	3.62E-02	4.59E-02	Detected
	Near field	B-1	3/31/2016	9.94E-02	4.09E-02	4.11E-02	Detected
	Near field	B-2	3/31/2016	6.01E-02	2.79E-02	3.14E-02	Detected
	Near field	B-3	3/31/2016	4.66E-02	3.90E-02	7.80E-02	Not detected
	Near field	B-4	4/8/2016	3.85E-02	2.58E-02	4.53E-02	Not detected
	Near field	B-5	4/8/2016	5.54E-02	3.60E-02	6.55E-02	Not detected
	Near field	B-6	3/30/2016	5.82E-02	2.80E-02	3.56E-02	Detected
	Near field	B-6 DUP	3/30/2016	4.41E-02	4.71E-02	9.62E-02	Not detected
	Near field	B-7	3/30/2016	3.50E-02	2.51E-02	4.11E-02	Not detected
	Near field	B-8	3/30/2016	5.01E-02	2.36E-02	1.84E-02	Detected
$^{239+240}Pu$	Near field	A-1	3/22/2016	7.00E-02	4.00E-02	6.78E-02	Detected
	Near field	A-2	3/22/2016	9.07E-02	3.82E-02	5.16E-02	Detected
	Near field	A-3	3/22/2016	2.07E-02	3.00E-02	6.56E-02	Not detected
	Near field	A-3 DUP	3/22/2016	4.16E-02	2.82E-02	4.70E-02	Not detected
	Near field	A-4	3/22/2016	7.38E-02	3.59E-02	5.34E-02	Detected
	Near field	A-5	3/22/2016	1.47E-01	5.18E-02	6.14E-02	Detected
	Near field	A-6	3/22/2016	1.08E-01	4.43E-02	4.45E-02	Detected
	Near field	A-7	3/22/2016	9.60E-02	4.55E-02	6.43E-02	Detected
	Near field	A-8	3/22/2016	1.19E-01	4.63E-02	6.76E-02	Detected
	Near field	B-1	3/31/2016	9.56E-02	4.36E-02	6.58E-02	Detected
	Near field	B-2	3/31/2016	1.35E-01	4.16E-02	2.50E-02	Detected
	Near field	B-3	3/31/2016	9.78E-02	5.46E-02	8.76E-02	Detected
	Near field	B-4	4/8/2016	1.35E-01	4.72E-02	4.98E-02	Detected
	Near field	B-5	4/8/2016	9.24E-02	3.78E-02	5.46E-02	Detected

Table 4-1: Activity concentrations of ^{241}Am, $^{239+240}$Pu and ^{238}Pu (Bq/kg) in soil samples collected from Near Field in 2016 (continued)

Radionuclides	Location	Grid Nodes	Sampling Date	Activity Bq/kg	Unc. (2σ) Bq/kg	MDC Bq/kg	Status
$^{239+240}$Pu	Near field	B-6	3/30/2016	1.15E-01	4.02E-02	2.80E-02	Detected
	Near field	B-6 DUP	3/30/2016	5.90E-02	2.96E-02	3.54E-02	Detected
	Near field	B-7	3/30/2016	1.05E-01	4.22E-02	5.25E-02	Detected
	Near field	B-8	3/30/2016	7.21E-02	4.16E-02	6.61E-02	Detected
^{238}Pu	Near field	A-1	3/22/2016	9.55E-03	1.69E-02	3.82E-02	Not detected
	Near field	A-2	3/22/2016	-1.10E-02	1.74E-02	5.52E-02	Not detected
	Near field	A-3	3/22/2016	-1.24E-02	3.42E-02	9.73E-02	Not detected
	Near field	A-3 DUP	3/22/2016	-2.96E-03	2.44E-02	6.65E-02	Not detected
	Near field	A-4	3/22/2016	-1.70E-02	2.67E-02	7.76E-02	Not detected
	Near field	A-5	3/22/2016	-2.60E-02	2.92E-02	8.90E-02	Not detected
	Near field	A-6	3/22/2016	-2.23E-02	3.16E-02	9.45E-02	Not detected
	Near field	A-7	3/22/2016	3.69E-03	3.38E-02	8.68E-02	Not detected
	Near field	A-8	3/22/2016	-1.66E-02	2.21E-02	6.76E-02	Not detected
	Near field	B-1	3/31/2016	-2.47E-02	2.78E-02	8.42E-02	Not detected
	Near field	B-2	3/31/2016	-1.62E-02	2.01E-02	6.34E-02	Not detected
	Near field	B-3	3/31/2016	9.31E-03	2.94E-02	7.38E-02	Not detected
	Near field	B-4	4/8/2016	9.42E-03	2.88E-02	7.05E-02	Not detected
	Near field	B-5	4/8/2016	7.31E-03	1.62E-02	3.86E-02	Not detected
	Near field	B-6	3/30/2016	-1.81E-02	2.10E-02	6.77E-02	Not detected
	Near field	B-6 DUP	3/30/2016	-2.07E-02	2.43E-02	7.53E-02	Not detected
	Near field	B-7	3/30/2016	6.03E-03	2.83E-02	7.09E-02	Not detected
	Near field	B-8	3/30/2016	0.00E+00	1.52E-02	4.55E-02	Not detected

Table 4-2: The background concentrations of ^{137}Cs, $^{239+240}$Pu and ^{241}Am (Bq/kg) in surface soil in the vicinity of the WIPP site

Location	Year	^{137}Cs	$^{239+240}$Pu	^{241}Am	Reference
100 M NW of WIPP Met. Tower	1991	0.00	0.00	-	Kenny et al., 1995
390 M east of WIPP exhaust	1990	7.4	0.37	-	Kenny et al., 1995
530 M south of WIPP exhaust	1994-95	0.00	0.74	-	Kenny et al., 1995
775 M west of WIPP exhaust	1990	3.7	0.37	-	Kenny et al., 1995
1000 M NW of WIPP exhaust	1989	7.4	0.00	-	Kenny et al., 1995
WIPP vicinity, Near Field	1998	0.31-5.96	0.015-0.22	0.002-0.13	CEMRC Data 1998
WIPP vicinity, Cactus Flats	1998	0.70- 14.8	0.013-0.51	0.007-0.26	CEMRC Data 1998
WIPP vicinity	1995	0-7.40	0.00-0.74	-	Kenny et al., 1995
Gnome site	1995	2.59-3090	4.4-48000	0.40-7600	Kenny et al., 1995
Gnome site	2002	45.9-2980	0.07-1550	0.04-3460	CEMRC Data 2005/2006
Distant Locations	1982-87	6.45-47.25	0.13-6.98	-	Krey and Beck, 1981

Table 4-3: Activity concentrations of isotopes of uranium (Bq/kg) in soil samples Collected from Near Field in 2016

Radionuclides	Location	Grid Nodes	Sampling Date	Activity Bq/kg	Unc. (2σ) Bq/kg	MDC Bq/kg	Status
^{234}U	Near field	A-1	3/22/2016	7.51E+00	8.86E-01	8.88E-02	Detected
	Near field	A-2	3/22/2016	4.99E+00	6.08E-01	8.23E-02	Detected
	Near field	A-3	3/22/2016	4.82E+00	6.22E-01	1.56E-01	Detected
	Near field	A-3 DUP	3/22/2016	4.89E+00	6.05E-01	1.29E-01	Detected
	Near field	A-4	3/22/2016	4.87E+00	6.10E-02	7.67E-02	Detected
	Near field	A-5	3/22/2016	5.83E+00	7.24E-01	9.17E-02	Detected
	Near field	A-6	3/22/2016	5.34E+00	6.69E-01	9.51E-02	Detected
	Near field	A-7	3/22/2016	5.95E+00	7.27E-01	8.98E-02	Detected
	Near field	A-8	3/22/2016	5.64E+00	6.98E-01	8.31E-02	Detected
	Near field	B-1	3/31/2016	7.84E+00	9.52E-01	9.27E-02	Detected
	Near field	B-2	3/31/2016	6.21E+00	7.38E-01	5.45E-02	Not Detected
	Near field	B-3	3/31/2016	6.15E+00	7.36E-01	6.97E-02	Detected
	Near field	B-4	4/8/2016	7.29E+00	8.80E-01	7.18E-02	Detected
	Near field	B-5	4/8/2016	5.06E+00	6.07E-01	4.35E-02	Detected
	Near field	B-6	3/30/2016	6.38E+00	7.65E-01	6.06E-02	Detected
	Near field	B-6 DUP	3/30/2016	5.86E+00	7.36E-01	9.54E-02	Detected
	Near field	B-7	3/30/2016	5.93E+00	7.09E-01	3.20E-02	Detected
	Near field	B-8	3/30/2016	6.67E+00	8.04E-01	7.19E-02	Detected
^{235}U	Near field	A-1	3/22/2016	3.35E-01	8.57E-02	5.84E-02	Detected
	Near field	A-2	3/22/2016	2.84E-01	7.64E-02	6.09E-02	Detected
	Near field	A-3	3/22/2016	2.40E-01	9.07E-02	1.13E-01	Detected
	Near field	A-3 DUP	3/22/2016	2.51E-01	7.89E-02	7.96E-02	Detected
	Near field	A-4	3/22/2016	2.58E-01	8.12E-02	8.19E-02	Detected
	Near field	A-5	3/22/2016	3.32E-01	9.78E-02	7.92E-02	Detected
	Near field	A-6	3/22/2016	2.59E-01	8.37E-02	8.69E-02	Detected
	Near field	A-7	3/22/2016	5.14E-01	1.15E-01	4.38E-02	Detected
	Near field	A-8	3/22/2016	2.98E-01	8.60E-02	6.78E-02	Detected
	Near field	B-1	3/31/2016	4.29E-01	1.11E-01	7.57E-02	Detected
	Near field	B-2	3/31/2016	3.16E-01	8.10E-02	6.12E-02	Detected
	Near field	B-3	3/31/2016	2.81E-01	7.50E-02	5.41E-02	Detected
	Near field	B-4	4/8/2016	3.63E-01	9.49E-02	6.64E-02	Detected
	Near field	B-5	4/8/2016	2.25E-01	6.55E-02	4.58E-02	Detected
	Near field	B-6	3/30/2016	4.00E-01	9.53E-02	5.16E-02	Detected

Table 4-3: Activity concentrations of isotopes of uranium (Bq/kg) in soil samples Collected from Near Field in 2016 (continued)

Radionuclides	Location	Grid Nodes	Sampling Date	Activity Bq/kg	Unc. (2σ) Bq/kg	MDC Bq/kg	Status
^{235}U	Near field	B-6 DUP	3/30/2016	2.60E-01	8.55E-02	7.79E-02	Detected
	Near field	B-7	3/30/2016	3.42E-01	8.92E-02	7.37E-02	Detected
	Near field	B-8	3/30/2016	5.84E-01	1.25E-01	5.66E-02	Detected
^{238}U	Near field	A-1	3/22/2016	7.18E+00	8.51E-01	1.02E-01	Detected
	Near field	A-2	3/22/2016	5.28E+00	6.40E-01	1.27E-01	Detected
	Near field	A-3	3/22/2016	4.77E+00	6.14E-01	1.72E-01	Detected
	Near field	A-3 DUP	3/22/2016	5.09E+00	6.33E-01	1.07E-01	Detected
	Near field	A-4	3/22/2016	5.23E+00	6.52E-01	1.10E-01	Detected
	Near field	A-5	3/22/2016	5.92E+00	7.35E-01	1.46E-01	Detected
	Near field	A-6	3/22/2016	5.55E+00	6.93E-01	1.51E-01	Detected
	Near field	A-7	3/22/2016	6.76E+00	8.18E-01	1.28E-01	Detected
	Near field	A-8	3/22/2016	5.81E+00	7.17E-01	1.09E-01	Detected
	Near field	B-1	3/31/2016	7.10E+00	8.69E-01	1.33E-01	Detected
	Near field	B-2	3/31/2016	6.71E+00	7.91E-01	6.27E-02	Detected
	Near field	B-3	3/31/2016	6.62E+00	7.87E-01	7.90E-02	Detected
	Near field	B-4	4/8/2016	7.54E+00	9.06E-01	7.14E-02	Detected
	Near field	B-5	4/8/2016	4.94E+00	5.96E-01	6.57E-02	Detected
	Near field	B-6	3/30/2016	6.44E+00	7.71E-01	6.96E-02	Detected
	Near field	B-6 DUP	3/30/2016	5.71E+00	7.22E-01	1.59E-01	Detected
	Near field	B-7	3/30/2016	6.64E+00	7.88E-01	6.44E-02	Detected
	Near field	B-8	3/30/2016	7.66E+00	9.15E-01	6.63E-02	Detected

Table 4-4: Activity concentrations of ^{137}Cs, ^{40}K and ^{60}Co (Bq/kg) in soil samples collected from Near Field in 2016

Radionuclides	Location	Grid Nodes	Sampling Date	Activity Bq/kg	Unc. (2σ) Bq/kg	MDC Bq/kg	Status
^{137}Cs	Near Field	A-1	3/22/2016	1.78E+00	1.80E-01	5.47E-01	Detected
	Near Field	A-2	3/22/2016	1.56E+00	1.75E-01	5.39E-01	Detected
	Near Field	A-3	3/22/2016	3.96E-01	1.60E-01	5.24E-01	Not detected
	Near Field	A-3 DUP	3/22/2016	7.16E-01	1.68E-01	5.41E-01	Detected
	Near Field	A-4	3/22/2016	1.35E+00	1.69E-01	5.26E-01	Detected
	Near Field	A-5	3/22/2016	2.62E+00	1.91E-01	5.51E-01	Detected
	Near Field	A-6	3/22/2016	1.85E+00	1.85E-01	5.62E-01	Detected
	Near Field	A-7	3/22/2016	1.50E+00	1.77E-01	5.48E-01	Detected
	Near Field	A-8	3/22/2016	2.77E+00	1.97E-01	5.64E-01	Detected

Table 4-4: Activity concentrations of ^{137}Cs, ^{40}K and ^{60}Co (Bq/kg) in soil samples collected from Near Field in 2016 (continued)

Radionuclides	Location	Grid Nodes	Sampling Date	Activity Bq/kg	Unc. (2σ) Bq/kg	MDC Bq/kg	Status
^{137}Cs	Near Field	B-1	3/31/2016	2.13E+00	7.14E-01	5.48E-01	Detected
	Near Field	B-2	3/31/2016	2.54E+00	2.00E-01	5.86E-01	Detected
	Near Field	B-3	3/31/2016	2.04E+00	2.00E-01	6.06E-01	Detected
	Near Field	B-4	4/8/2016	1.93E+00	1.89E-01	5.56E-01	Detected
	Near Field	B-5	4/8/2016	1.33E+00	1.62E-01	5.03E-01	Detected
	Near Field	B-6	3/30/2016	2.08E+00	1.79E-01	5.31E-01	Detected
	Near Field	B-6 DUP	3/30/2016	1.56E+00	1.75E-01	5.40E-01	Detected
	Near Field	B-7	3/30/2016	2.38E+00	1.92E-01	5.64E-01	Detected
	Near Field	B-8	3/30/2016	9.08E-01	1.73E-01	5.53E-01	Detected
^{40}K	Near Field	A-1	3/22/2016	2.40E+02	1.33E+01	5.09E+00	Detected
	Near Field	A-2	3/22/2016	1.60E+02	1.05E+01	5.17E+00	Detected
	Near Field	A-3	3/22/2016	1.67E+02	1.09E+01	5.04E+00	Detected
	Near Field	A-3 DUP	3/22/2016	1.73E+02	1.13E+01	4.95E+00	Detected
	Near Field	A-4	3/22/2016	1.59E+02	1.04E+01	4.90E+00	Detected
	Near Field	A-5	3/22/2016	2.02E+02	1.31E+01	5.02E+00	Detected
	Near Field	A-6	3/22/2016	1.89E+02	1.23E+01	5.24E+00	Detected
	Near Field	A-7	3/22/2016	2.07E+02	1.34E+01	5.04E+00	Detected
	Near Field	A-8	3/22/2016	2.16E+02	1.40E+01	5.20E+00	Detected
	Near Field	B-1	3/31/2016	2.26E+02	1.46E+01	5.15E+00	Detected
	Near Field	B-2	3/31/2016	2.31E+02	1.50E+01	5.32E+00	Detected
	Near Field	B-3	3/31/2016	2.27E+02	1.47E+01	5.20E+00	Detected
	Near Field	B-4	4/8/2016	2.37E+02	1.53E+01	5.33E+00	Detected
	Near Field	B-5	4/8/2016	1.26E+02	8.30E+00	4.64E+00	Detected
	Near Field	B-6	3/30/2016	1.74E+02	1.14E+01	4.97E+00	Detected
	Near Field	B-6 DUP	3/30/2016	1.69E+02	1.10E+01	5.20E+00	Detected
	Near Field	B-7	3/30/2016	2.08E+02	1.35E+01	5.47E+00	Detected
	Near Field	B-8	3/30/2016	2.03E+02	1.32E+01	4.91E+00	Detected
^{60}Co	Near Field	A-1	3/22/2016	1.92E-01	1.79E-01	5.90E-01	Not detected
	Near Field	A-2	3/22/2016	1.19E-01	1.73E-01	5.73E-01	Not detected
	Near Field	A-3	3/22/2016	2.10E-01	1.74E-01	5.72E-01	Not detected
	Near Field	A-3 DUP	3/22/2016	7.89E-03	1.77E-01	5.88E-01	Not detected
	Near Field	A-4	3/22/2016	1.18E-01	1.73E-01	5.73E-01	Not detected

Table 4-4: Activity concentrations of ^{137}Cs, ^{40}K and ^{60}Co (Bq/kg) in soil samples collected from Near Field in 2016 (continued)

Radionuclides	Location	Grid Nodes	Sampling Date	Activity Bq/kg	Unc. (2σ) Bq/kg	MDC Bq/kg	Status
^{60}Co	Near Field	A-5	3/22/2016	1.22E-01	1.57E-01	5.17E-01	Not detected
	Near Field	A-6	3/22/2016	2.40E-01	1.92E-01	6.42E-01	Not detected
	Near Field	A-7	3/22/2016	2.04E-01	1.82E-01	6.00E-01	Not detected
	Near Field	A-8	3/22/2016	1.56E-01	1.87E-01	6.19E-01	Not detected
	Near Field	B-1	3/31/2016	1.29E-01	1.86E-01	6.15E-01	Not detected
	Near Field	B-2	3/31/2016	2.67E-02	1.92E-01	6.37E-01	Not detected
	Near Field	B-3	3/31/2016	6.27E-02	1.98E-01	6.55E-01	Not detected
	Near Field	B-4	4/8/2016	2.15E-01	2.01E-01	6.69E-01	Not detected
	Near Field	B-5	4/8/2016	2.10E-01	1.61E-01	5.29E-01	Not detected
	Near Field	B-6	3/30/2016	3.34E-02	1.75E-01	5.81E-01	Not detected
	Near Field	B-6 DUP	3/30/2016	1.66E-01	1.73E-01	5.71E-01	Not detected
	Near Field	B-7	3/30/2016	1.63E-01	1.84E-01	6.09E-01	Not detected
	Near Field	B-8	3/30/2016	2.60E-01	1.79E-01	5.90E-01	Not detected

CHAPTER 5

Drinking Water Monitoring

Drinking water is typically defined as water that is safe enough to be consumed by humans or to be used with low risk of immediate or long term impact to human health. For this reason, the quality of drinking water available in the area surrounding of the WIPP site is routinely checked to assure the public that health and environmental standards are met and to identify any changes in water quality which might have a negative impact on public health and/or the environment. Aquifers in the region surrounding the WIPP include the Dewey Lake, the Culebra-Magenta, the Ogallala, the Dockum, the Pecos River alluvium, and the Capitan Reef. The main Carlsbad water supply is the Sheep Draw well field whose primary source is the Capitan Reef aquifer. The Hobbs and WIPP (Double Eagle) public water supply systems are drawn from the Ogallala aquifer, while the Loving, Malaga, and Otis public water supply wells are drawn from deposits that are hydraulically linked to the flow of the Pecos River. An additional CEMRC sampling site, situated at a private well located seven miles southwest of the WIPP, which obtains its water from the Culebra aquifer has been historically sampled and analyzed; however, this sampling site has been dry since approximately 2001.

In 1974, the United States Congress passed the Safe Drinking Water Act. This law requires the U.S. Environmental Protection Agency (EPA) to determine the safe levels of contaminants in U.S. drinking water. The EPA conducts research of drinking water to determine the level of a contaminant that is safe for a person to consume over a lifetime and that a water system can reasonably be required to remove from it, given present technology and resources. This safe level is called the maximum contaminant level (MCL). MCLs in drinking water have been established for a variety of radionuclides. For radium, the MCL has been set at 5 pCi/L (picocuries per liter, a unit of measure for levels of radiation). The MCL for gross alpha radiation is 15 pCi/L (not including radon and uranium), and the maximum limit for gross beta radiation is 50 pCi/L. In addition to causing cancer, exposure to uranium in drinking water may cause toxic effects to the kidney. Based on human kidney toxicity data, the MCL for uranium is 30 □g/L. Additionally, the EPA says that a treatment system would be considered vulnerable if it contained 50 pCi/L of uranium. Although the MCL applies only to public drinking water sources, it can give those who use private wells an idea of what an appropriate level of a contaminant should be for private water sources also.

During 2016, the CEMRC drinking water samples were collected from the major drinking water supplies used by communities in the WIPP region. The sources included the community water supplies of Carlsbad (Sheep Draw), Carlsbad (Double Eagle), Loving, Otis, Hobbs, and Malaga. These locations are shown in Figure 5-1. The drinking water wells in the vicinity of the WIPP provide water primarily for livestock as well as industrial usage by oil and gas production

operations and are subject to monitoring studies conducted by various groups. While the CEMRC sampling locations are not likely to be affected by any WIPP radioactivity releases, the samples are collected and analyzed by the CEMRC annually because water is a primary vector in the food chain. As with community air sampling, the verification of the absence of WIPP-related radionuclides from CEMRC drinking water samples collected provides further public assurance of the safety of the WIPP and its negligible impact on the local populace or the environment.

History of CEMRC's Drinking Water Monitoring

CEMRC began collecting drinking water samples for radiochemical analyses in 1997 and inorganic analyses on drinking water samples commenced in 1998. Summaries of methods, data, and results from previous samplings were reported in earlier CEMRC reports and can be found on the CEMRC website (http://www.cemrc.org) under the annual reports tab. Drinking water samples were not collected during 2004 and 2006 and the Malaga water system was added to the CEMRC sampling sites in 2011. Present results as well as the results of previous analyses of drinking water were consistent for each source across sampling periods, and were found to be below levels specified under the Safe Drinking Water Act.

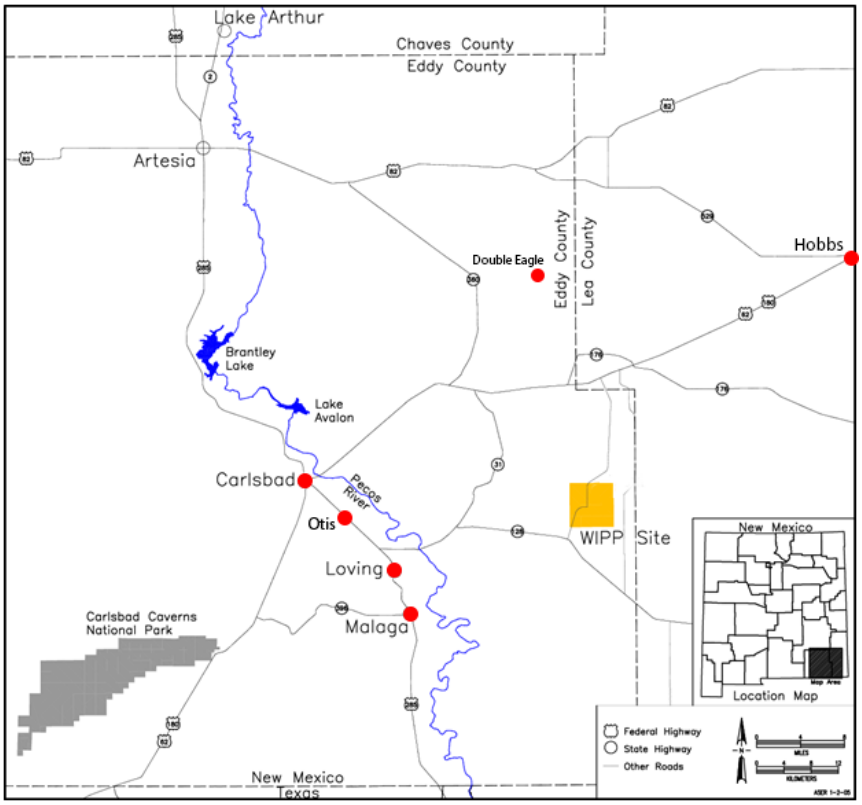


Figure 5-1: Drinking water sampling locations

It is important to note that after more than ten years of monitoring, isotopes of ^{238}Pu, $^{239+240}$Pu, and ^{241}Am have never been detected above MDC in any of the samples collected from sampling sites around the WIPP site. Although uranium has been detected above the MDC, the observed activity indicates its presence in regional drinking water samples is most likely from natural sources. For most people in the world, the intake of uranium through food is around 1μg/day. The worldwide average of dietary uranium is estimated at 1.3 μg/day from which the portion from drinking water is 0.2 μg/day or 15.4% (UNSCEAR, 2001). Thus drinking water is not usually the main source of ingested uranium. The CEMRC Monitoring results for drinking water analyses conducted to date **show no increase in the levels of radionuclides or inorganics that could be attributed to the WIPP related activities.**

Drinking water monitoring following the 2014 WIPP Radiation Release Event

Drinking water samples collected from the same locations following the February 14, 2014 underground radiation release event at the WIPP had uranium concentrations in the range from 10.6-72.4 mBq/L for ^{238}U, 0.58-3.46 mBq/L for ^{235}U, and 28-171 mBq/L for ^{234}U. The detailed monitoring results are published in CEMRC Annual Report 2014 and are available at (www.cemrc.org/Annual Report). The levels detected were consistent with those measured previously from these locations. These sampling locations are not likely to be affected by any WIPP-related radiation releases; however, the verification of no WIPP radionuclides in drinking waters continues to demonstrate the absence of adverse effects to the local and wider public or to the environment from the February 14, 2014 underground radiation release event at the WIPP. Further, the isotopes of plutonium (^{238}Pu and $^{239+240}$Pu) and ^{241}Am, the main radionuclides released from the WIPP repository, were not detected in any of the drinking water samples collected in 2014.

Analyses reported herein for are for 2016 drinking water samples only. These samples were analyzed for radionuclides including alpha and gamma emitting radionuclides of interest to the WIPP. In addition, inorganic studies were performed separately and include elemental analysis as well as an analysis for mercury. **The 2016 monitoring results for drinking water analyses continue to show no increase in the levels of radionuclides or inorganics that could be attributed to the February 2014 underground radiological event at WIPP.**

Sampling, Sample Preparation, and Measurements

All drinking water samples were processed according to CEMRC protocols for the collection, handling, and preservation of drinking water. This year, the drinking water samples were collected in July of 2016. The following samples were taken from each sampling location: (1) 8L for gamma and alpha analyses, (2) 1L for elemental analyses, (3) 1L for anion tests, and (4) 500mL for mercury analysis. None of the samples were filtered before analysis. Current methods used for the various analyses are summarized in Table 5-1. Basic information about contaminants in drinking water is listed in Table 5-2.

For radioactive analyses, two aliquots were taken from each 8L sample: (a) Approximately 2L for gamma analyses and (b) 1L for alpha analyses. Both aliquots were acidified to approximately pH = 2 with nitric acid upon collection to avoid losses through microbial activity and adsorption onto the vessel walls. The first aliquot was transferred to 2L Marinelli beakers for the measurement of the gamma-emitting radionuclides potassium (^{40}K), cobalt (^{60}Co), and cesium (^{137}Cs), by gamma spectroscopy using a high purity germanium (HPGe) detector. Before collecting the measurements, the gamma system was calibrated for energy and efficiency to enable both qualitative and quantitative analysis of the water samples. The energy and efficiency calibrations were carried out using a mixed standards material from Eckert and Ziegler, Analytics (GA) in the energy range between 60 to 2000 keV. The counting time for each sample was 48 hours.

The second, 1L aliquot, was used for alpha analysis of uranium (U) and transuranic radionuclides. Tracers consisting of uranium, americium, and plutonium (^{232}U, ^{243}Am, and ^{242}Pu) were added and the samples were digested using concentrated nitric and hydrochloric acid. The samples were then heated to dryness and wet-ashed using concentrated nitric and hydrogen peroxide. The separation process began by co-precipitation on $Fe(OH)_3$. Plutonium isotopes were separated and purified using a two-column anion exchange resin (Dowex1× 8, Eichrom, 100-200 mesh), while TRU chromatography columns were used for the separation of Am and U. The samples were then micro-co-precipitated using neodymium fluoride (NdF_3) and deposited onto planchets for counting uranium/transuranics by alpha spectroscopy for five days.

The 1L samples collected for elemental analysis were preserved with distilled nitric acid during sample collection. Due to the elevated calcium (Ca) and sodium (Na) levels in all of the 2016 samples, they were diluted using a similar nitric acid matrix prior to analysis by Inductively-Coupled Plasma Mass Spectrometer (ICP-MS). For Mercury analysis, the 500mL samples were preserved with a bromomonochloride solution and analyzed directly by ICP-MS.

Each 1L sample used for anion analysis was refrigerated immediately upon arrival and analyzed within 48 hours of collection. No preservatives were added to the samples used for anion analysis. However, due to the high chloride and sulfate content, all of the samples were diluted with ultrapure water prior to analysis.

Table 5-1: Drinking Water Parameters, Methods, and Detection Levels used to Analyze Samples from all Locations

Method/Parameters	Analytes of Interest	Typical Detection Limits
Gross alpha/beta EPA 900.0	(Under Development)	0.037-0.11 Bq/L*
Gamma emitters	^{60}Co, ^{137}Cs and ^{40}K	0.03-1.0 Bq/L*
Alpha emitters	$^{239+240}Pu$, ^{238}Pu, ^{241}Am, ^{234}U, ^{238}U, ^{235}U	0.001-0.002 Bq/L*
Elemental analysis EPA 200.8	Over 30 different metals	Varies by element**
Anions (EPA 300.0)	F^-, Cl^-, Br^-, NO_2^-, NO_3^-, PO_4^{3-}, SO_4^{2-}	1.5 – 16.9 µg/L **
Mercury (EPA 200.8)	Hg	0.085 µg/L**

* Detection limits may vary depending on sample volume, solid concentrations, counting system and time
** Detection limits are determined annually

Table 5-2: General Information about Inorganic Contaminants in Drinking Water from the EPA

Contaminant	Minimum Contaminants Level	Potential Health Effects from Long-term Exposure	Sources of Drinking Water Contaminants
Antimony, Sb	0.006mg/L	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic, As	0.010mg/L	Skin damage or problems with circulatory systems, and may have increased risk of cancer	Erosion of natural deposits; runoff from orchards; runoff from glass & electronics production wastes
Barium, Ba	2mg/L	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium, Be	0.004 mg/L	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium, Cd	0.005 mg/L	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chloride, Cl^-	250 mg/L*[2]	N/A	N/A
Chromium, Cr (total)	0.1 mg/L	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits

Table 5-2: General Information about Inorganic Contaminants in Drinking Water from the EPA (continued)

Contaminant	Minimum Contaminants Level	Potential Health Effects from Long-term Exposure	Sources of Drinking Water Contaminants
Copper, Cu	1.3 mg/L	**Short term exposure**: gastrointestinal distress. **Long term exposure**: liver or kidney damage	Corrosion of household plumbing systems; erosion of natural deposits
Fluoride, F^-	4.0 mg/L	Bone disease; children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead, Pb	0.015 mg/L	**Infants and children**: delays in physical or mental development; **Adults**: kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits
Mercury, Hg (Inorganic)	0.002 mg/L	Kidney damage	Erosion of natural deposits; discharge from refineries; runoff from landfills and croplands
Nitrate (measured as N)	10 mg/L	Shortness of breath and blue-baby syndrome	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Nitrite (measured as N)	1 mg/L		
Selenium, Se	0.05 mg/L	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum and metal refineries; erosion of natural deposits; discharge from mines
Sulfate, SO_4^{2-}	250 mg/L*[2]	N/A	N/A
Thallium, Tl	0.002 mg/L	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories
Uranium, U	30 µg/L	Increased risk of cancer; kidney toxicity	Erosion of natural deposits

* U.S. EPA: United States Environmental Protection Agency (2012), Drinking Water Contaminants

*[2] Secondary regulations are not enforceable.

N/A = Not available

Data Reporting

The activities of the actinides and gamma radionuclides are reported as activity concentration in Bq/L. Activity concentration is calculated as the activity of radionuclides detected in Becquerel (Bq) divided by weight of the drinking water in liters (L).

For each type of inorganic analysis (elemental, mercury, and anions), aliquots were blank-corrected after the application of dilution factors. As per the CEMRC procedure, only concentrations above laboratory MDC values are reported. Results for all inorganic analyses are reported in units of parts per billion (ppb).

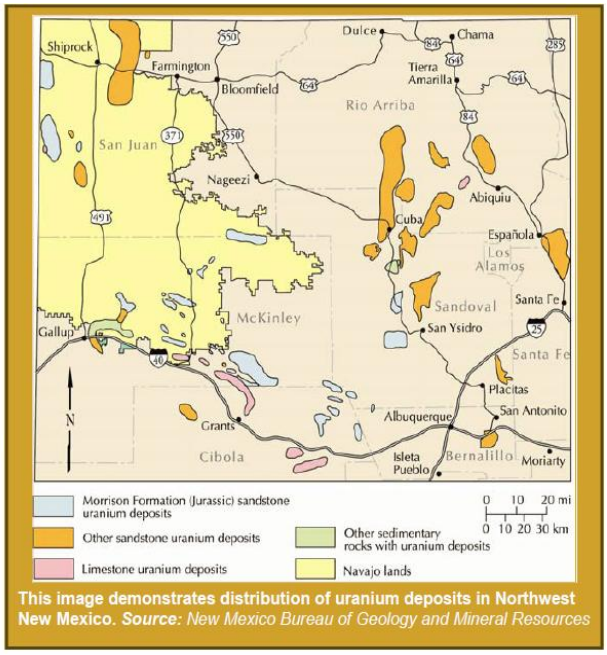
Radiological Monitoring Results

The activity concentrations of ^{238}Pu, $^{239+240}$Pu, ^{241}Am, ^{234}U, ^{235}U, and ^{238}U in regional drinking water samples collected in 2016 are listed in Table 5-3. The alpha radionuclides, ^{238}Pu, $^{239+240}$Pu, and ^{241}Am have not been detected in any of the drinking water samples above the MDC since monitoring commenced in 1997. The federal and state action level for gross alpha emitters, which includes isotopes of Pu and U, is 15 pCi/L (0.56 Bq/L). This level measured is over 10,000 times the MDCs used at CEMRC. The historical concentrations of $^{239+240}$Pu, ^{238}Pu and ^{241}Am measured in the drinking water in the vicinity of the WIPP site are shown in Figures 5-2 through 5-9.

Isotopes of naturally occurring uranium were detected in all of the drinking water samples in 2016 as shown in Table 5-4. Uranium in the environment occurs naturally as three radioactive isotopes: ^{238}U (99.27%), ^{235}U (0.72%) and ^{234}U (0.005%). They have long half-lives ($t_{1/2}$) that allow them to be transported to water supplies. The isotopes of uranium are also found in the earth's crust with a natural abundance of about 0.0004 % (Hursh et. al, 1973) in rocks and minerals such as granite, metamorphic rocks, lignite, monazite sand; phosphate deposits; as well as in uranium minerals such as uraninite, carnotite and pitchblende. It is also present as a trace element in coal, peat, asphalt and in some phosphate fertilizers at a level of about 100 µg/g or 2.5 Bq/g (Hess et. al, 1985). All of these sources can come in contact with water which may be used for drinking purposes. Thus it is expected that some drinking and surface waters sources will contain concentrations of uranium. The natural level of uranium in water can also be enhanced due to human activity. For example, the increased concentration of natural radionuclides in water can be caused by the intensive use of phosphate fertilizers in agriculture. The average phosphate fertilizers contains about 100 µg/g (or 24.8 Bq/g), if it is naturally occurring uranium (Cothern, and Lappenbusch, 1983), which can leach from the soil to nearby rivers and lakes (Fleischer, 1980; UNSCEAR, 1982). Additionally, contamination may be caused by catalysts, staining pigments, burning of fossil fuel (oil and coal) and the manufacture and use of phosphate fertilizers that contain uranium (WHO, 2005).

Despite its widespread abundance, uranium has not been shown to be an essential element for humans (Hursh et. al, 1973). The major health effect of uranium is its chemical toxicity rather than its radiological hazard. The chemical toxicity of uranium is considered to be similar to lead. The primary target organ from chronic (long-term) ingestion of uranium is kidney damage; however, liver and thyroid damage can also result. Regardless, radiological impacts from the ingestion of uranium continues to be the subject of ongoing research and debate.

Uranium levels are naturally high in many areas in the USA. Uranium contaminated drinking water is a common problem, particularly in the Western United States, including New Mexico. The map shown on the right highlights the major uranium deposits in New Mexico. Natural uranium mineral deposits are concentrated in northern Santa Fe County, the Grants-Gallup area, and in other areas within the State. These mineral deposits can leach uranium into ground water. From the early 1950s until the early 1980s, New Mexico had the second largest uranium ore reserves of any state in the United States (after Wyoming). Although, no uranium ore has been mined in New Mexico since 1998, there are many areas within New Mexico with elevated levels of uranium present in their groundwater. According to the EPA, the MCL for uranium in drinking Water is 30 ug/L. Despite this limit, water wells in several New Mexico communities show uranium levels three to six times higher than federal recommended levels for drinking water. Prior to 1980, uranium in drinking water was measured only when contamination from industrial sources was suspected. However, concerns over the radiological quality of drinking water have led to an increased demand for real data assessment. Further, considering the importance of water for human consumption, its quality has to be assured and regularly controlled; however, bathing in water with elevated levels of uranium is not considered to be a health risk. Cothern and Lappenbusch, 1983, conducted an extensive investigation of radioactivity in drinking water in the US. Of the 59,812 community drinking water supplies in the US, a projected 25 to 650 exceeded a uranium concentration of 0.74 Bq/L; 100 to 2,000 exceeded 0.37 Bq/L; and 2,500 to 5,000 exceeded 0.185 Bq/L. A survey conducted by European Food safety Authority (EFSA) found average uranium concentrations in the 5,474 tap water samples collected from various European countries to be about 0.055 Bq/L.



This image demonstrates distribution of uranium deposits in Northwest New Mexico. *Source:* *New Mexico Bureau of Geology and Mineral Resources*

Map 1: Major uranium deposits in New Mexico

Measured values for the drinking water samples collected in the vicinity of the WIPP site ranged from 7.8-66.1 mBq/L for for ^{238}U, 0.34-4.99 mBq/L for ^{235}U, and 20.9-170 mBq/L for ^{234}U. **These uranium activity concentrations are well below the EPA recommended level of 746 mBq/L**

and are within the range expected in waters from this region. According to the United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR, 2008, the ^{238}U concentrations in drinking water is about 0.5-149 mBq/L in the US, 0.74-1190 mBq/L in Germany, and 0.25-1389 mBq/L in China. The worldwide reference value for ^{238}U in drinking water is about 2 mBq/L. The levels detected in these drinking water sources were also within the range expected in the US. For comparison purposes, the variation of uranium concentrations in drinking water sources around the World is summarized in Table 5-5.

The activity concentrations of ^{234}U, ^{235}U, and ^{238}U in drinking water collected from the six sources in 2016 are presented in Figure 5-10. The greatest variations appear in the amounts of ^{235}U. The low activity concentration of ^{235}U in the water samples is consistent with the lower activity concentration of ^{235}U in the natural environment as compared to the activity concentrations of ^{234}U and ^{238}U. The highest activity concentrations were found in Malaga and Otis waters. Figure 5-11 shows the total uranium activity concentration at each location.

It has been reported that the activity of uranium in natural water from ^{234}U is higher than that of ^{238}U. The $^{234}U/^{238}U$ activity ratio usually ranges between 1.0 and 3.0 (Cherdynstev et al, 1971; Gilkeson et al, 1982). According to the most recent reports, the fixed mass ratio and fixed activity ratios are still used for reporting the activity of natural uranium. The isotopic composition of natural uranium activities for ^{234}U, ^{235}U, and ^{238}U are 48.9, 2.2, and 48.9 %, respectively (IAEA, 1989). In radiochemical equilibrium, natural activity ratios are typically unity (1.0) for $^{234}U/^{238}U$ and 0.045 for $^{235}U/^{238}U$ (Pimple et al, 1992). However, many studies looking at ^{238}U and ^{234}U in natural bodies of water indicate that these isotopes do not occur in equilibrium and that, with a few exceptions, waters typically contain more ^{234}U than ^{238}U (Cothern et al, 1983; Skwarzec et al, 2002). Higher activity of ^{234}U in water is the result of the ^{234}U atom displacement from the crystal lattice. The recoil atom, ^{234}U, is liable to be oxidized to the hexavalent stage and can be leached into the water phase more easily than its parent nuclide ^{238}U. The oxidation of U(IV) to U(VI) is an important step in leaching, because compounds containing U(VI) have a higher solubility due to the formation of strong complexes between uranyl and carbonate ions (UNSCEAR, 1977). All U(IV) compounds of uranium are practically insoluble.

The average activity ratio of $^{235}U/^{238}U$ in the water samples collected around the WIPP site ranged from 0.044-0.081. The natural ratio is reported to be 0.045 in nature. The $^{235}U/^{238}U$ ratio in environmental samples differing from the natural ratio results from anthropogenic nuclear activities. Figure 5-12 shows the $^{234}U/^{238}U$ ratios in the drinking water samples collected in 2016. The results of the activity ratios in this study compared very well with data observed in other countries as shown in Table 5-6. The calculated $^{234}U/^{238}U$ activity ratio varies between 2.13 to 3.16 which means that two isotopes are not in radioactive equilibrium. The $^{234}U/^{238}U$ activity ratio measured in regional drinking water since 1998 are shown in Figure 5-13. The historical activity concentrations of ^{234}U, ^{235}U and ^{238}U measured at each sites in the regional drinking water are summarized in Tables 5-7 through 5-12.

Gamma Radionuclides in the Drinking Water

The analysis data for the gamma isotopes are presented in Table 5-13. As shown in the Table 5-13, the naturally occurring gamma-emitting radionuclide, ^{40}K is not detected in any of the drinking water samples collected in 2016. In 2014, CEMRC had detected ^{40}K in Hobbs drinking water sample at a level of (1.35 Bq/L). Potassium-40 was also detected in drinking water samples collected from Carlsbad, Malaga and Otis in 2013. This naturally occurring gamma-emitting radionuclide is ubiquitous in nature, therefore an occasional detection of ^{40}K in drinking water is not unusual. There was no significant difference between concentrations of ^{40}K among sampling locations and the values fell within the range of concentrations observed previously in these drinking water locations. The other two gamma radionuclides (^{137}Cs and ^{60}Co) were not detected in any of the drinking water samples (Table 5-13). Since these isotopes were not detected, no comparisons between years or among locations were performed.

Radiation Dose Estimation

Given the natural uranium activity found within the drinking waters studied, it is necessary to provide context and values for these low but traceable quantities. Assuming that a person drinks about 2.5 liters of water per day, the annual effect dose (D) resulting from consumption of the water investigated in the present study can be calculated using the following formula:

$$D = K*G*C*T$$

where D is the dose via ingestion (in Sv); K is the ingestion dose conversion factor of the specific radionuclide (Sv/Bq); G is the water consumption per day per person; C is the concentration of the specific radionuclide (Bq/L) and T is the duration of consumption, here it is one year (365 days). Ingestion dose conversion factors (Sv/Bq) for adults (20-70 years) used in the calculations were taken from the International Commission on Radiological Protection (ICRP) publication and were equal to 4.5×10^{-8} for ^{238}U, 4.7×10^{-8} for ^{235}U and 4.9×10^{-8} for ^{234}U. The calculated effective doses for the analyzed drinking water samples were in the range of 2.1-2.9 μSv/Bq for Carlsbad, 2.3-6.3 μSv/Bq for Double Eagle, 4.2- 11.3 μSv/Bq for Hobbs, 10.1-14.0 μSv/Bq for Otis, and 6.2-8.1 μSv/Bq for Loving as shown in Figure 5-14. The overall annual effective dose contributions due to intake of uranium isotopes were below the WHO and IAEA reference value (100 μSv/y) for drinking water (WHO, 2004). For most people in the world, the intake of uranium through food is around 1 g/day. The worldwide average of dietary uranium is estimated at 1.3 g/day from which the portion from drinking water is 0.2 g/day. Thus drinking water is not usually the main source of ingested uranium.

Table 5-3: ^{241}Am, $^{239+240}$Pu and ^{238}Pu Concentrations Measured in Drinking Water in 2016

Radionuclide	Location	Activity Bq/L	Unc (2-sig) (Bq/L)	MDC (Bq/L)	Status
^{241}Am	Carlsbad	1.15E-04	9.31E-05	1.54E-04	Not Detected
	Otis	4.58E-05	6.84E-05	1.42E-04	Not Detected
	Loving	-6.66E-05	9.45E-05	3.14E-04	Not Detected
	Hobbs	1.11E-04	9.70E-05	1.67E-04	Not Detected
	Hobbs (Dup)	1.17E-04	1.10E-04	2.20E-04	Not Detected
	Double Eagle	8.37E-05	8.67E-05	1.69E-04	Not Detected
	Malaga	9.49E-05	1.27E-04	2.76E-04	Not Detected
	Blank	9.01E-05	1.01E-04	2.04E-04	Not Detected
$^{239+240}$Pu	Carlsbad	8.30E-05	1.02E-04	1.92E-04	Not Detected
	Otis	6.07E-05	1.72E-04	4.28E-04	Not Detected
	Loving	1.72E-11	1.02E-04	2.87E-04	Not Detected
	Hobbs	0.00E+00	9.88E-05	2.68E-04	Not Detected
	Hobbs (Dup)	8.65E-05	8.25E-05	1.49E-04	Not Detected
	Double Eagle	5.19E-05	6.38E-05	1.21E-04	Not Detected
	Malaga	8.66E-05	9.78E-05	1.59E-04	Not Detected
	Blank	-2.65E-04	3.25E-04	8.93E-04	Not Detected
^{238}Pu	Carlsbad	-1.04E-04	1.61E-04	4.88E-04	Not Detected
	Otis	1.45E-11	1.21E-04	3.64E-04	Not Detected
	Loving	-5.42E-05	1.19E-04	3.62E-04	Not Detected
	Hobbs	0.00E+00	6.98E-05	2.01E-04	Not Detected
	Hobbs (Dup)	-2.47E-05	4.95E-05	1.74E-04	Not Detected
	Double Eagle	0.00E+00	3.67E-05	1.21E-04	Not Detected
	Malaga	-4.33E-05	1.06E-04	3.44E-04	Not Detected
	Blank	1.57E-11	8.82E-05	2.65E-04	Not Detected

Table 5-4: Uranium Isotope Concentrations Measured in Drinking Water in 2016

Radionuclide	Location	Activity Bq/L	Unc (2-sig) (Bq/L)	MDC (Bq/L)	Status
^{234}U	Carlsbad	3.34E-02	3.92E-03	3.05E-04	Detected
	Otis	2.70E-02	3.31E-03	2.46E-04	Detected
	Loving	7.05E-02	8.28E-03	3.33E-04	Detected
	Hobbs	1.05E-01	1.22E-02	3.47E-04	Detected
	Hobbs (Dup)	9.69E-02	1.14E-02	4.45E-04	Detected
	Double Eagle	5.14E-02	6.09E-03	3.93E-04	Detected
	Malaga	1.47E-01	1.77E-02	5.22E-04	Detected
	Blank	1.24E-03	3.30E-04	3.35E-04	Detected
^{235}U	Carlsbad	9.90E-04	3.07E-04	2.64E-04	Detected
	Otis	1.44E-03	3.96E-04	2.58E-04	Detected
	Loving	1.23E-03	3.97E-04	4.12E-04	Detected
	Hobbs	2.48E-03	6.03E-04	3.80E-04	Detected
	Hobbs (Dup)	3.82E-03	7.89E-04	3.85E-04	Detected
	Double Eagle	1.19E-03	3.75E-04	2.89E-04	Detected
	Malaga	2.36E-03	6.40E-04	3.18E-04	Detected
	Blank	7.37E-05	1.48E-04	3.47E-04	Not Detected
^{238}U	Carlsbad	1.23E-02	1.60E-03	4.84E-04	Detected
	Otis	1.13E-02	1.55E-03	4.59E-04	Detected
	Loving	2.23E-02	2.84E-03	5.04E-04	Detected
	Hobbs	4.44E-02	5.39E-03	4.38E-04	Detected
	Hobbs (Dup)	4.54E-02	5.54E-03	3.84E-04	Detected
	Double Eagle	1.96E-02	2.52E-03	3.66E-04	Detected
	Malaga	5.43E-02	6.82E-03	4.81E-04	Detected
	Blank	2.23E-04	2.62E-04	5.85E-04	Not Detected

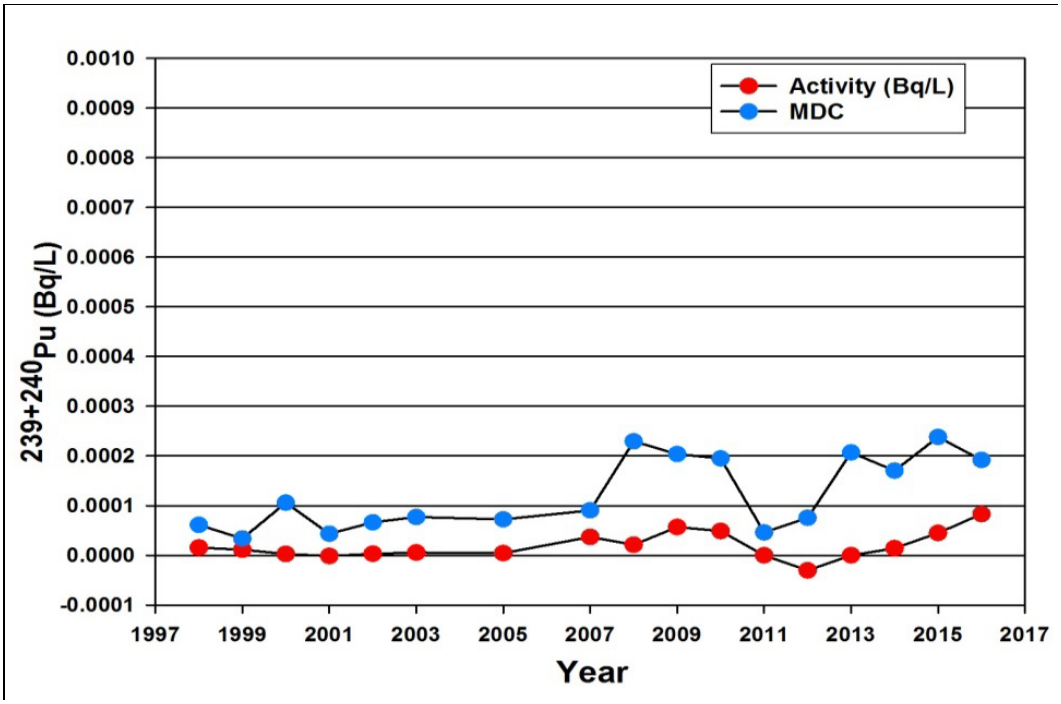


Figure 5-2: $^{239+240}$Pu in Carlsbad Drinking Water from 1998 – 2016

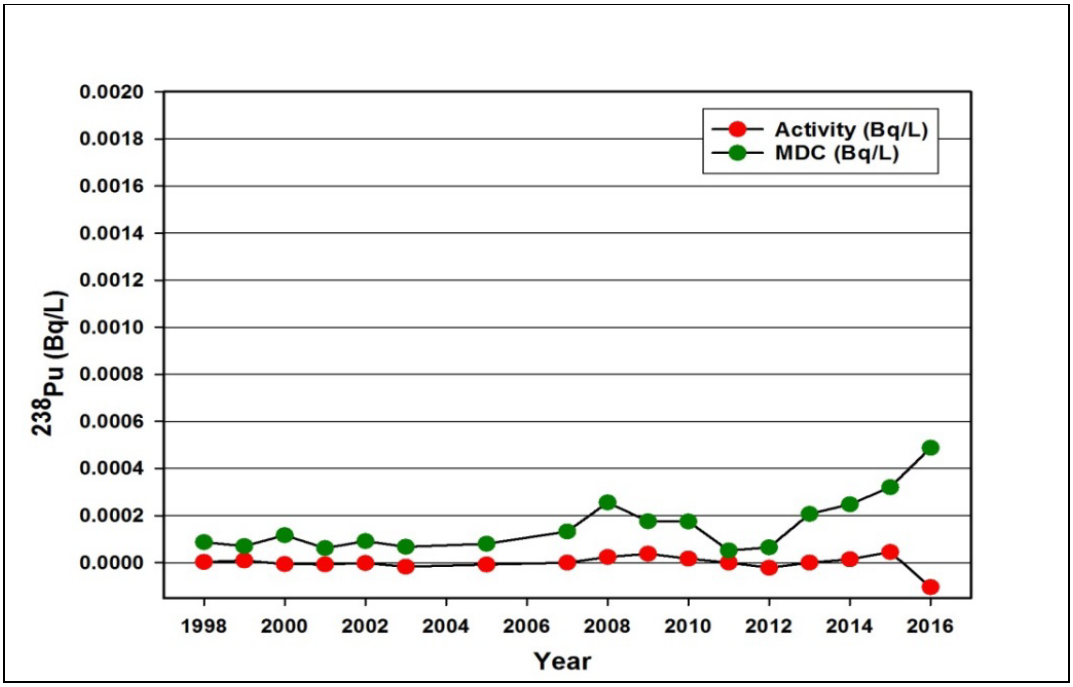


Figure 5-3: ^{238}Pu in Carlsbad Drinking Water from 1998 – 2016

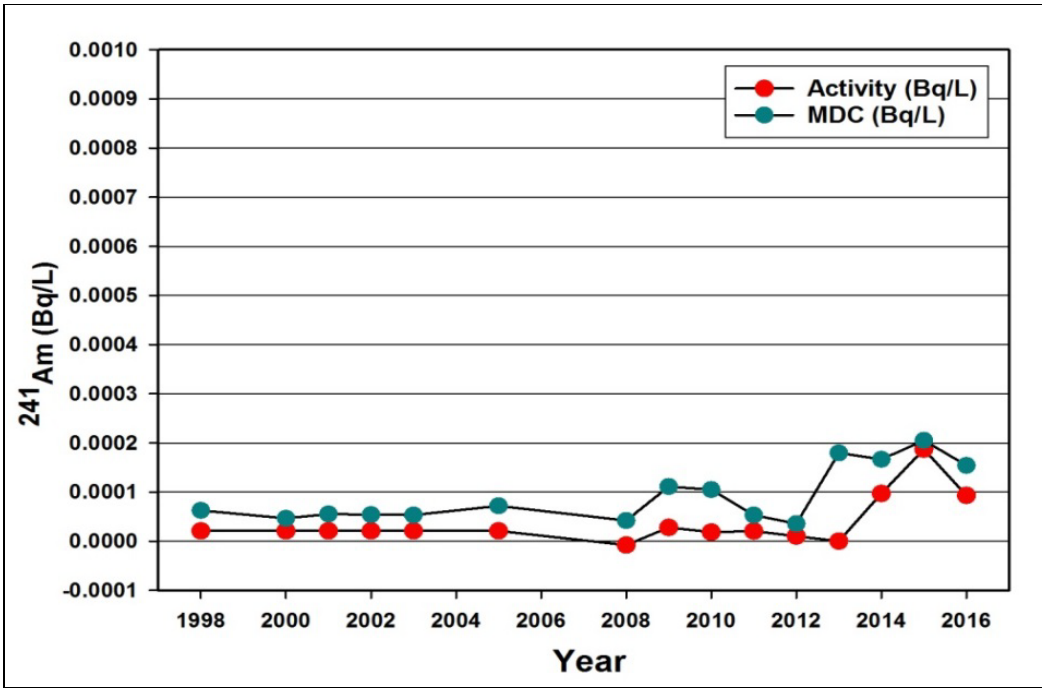


Figure 5-4: ^{241}Am in Carlsbad Drinking Water from 1998 – 2016

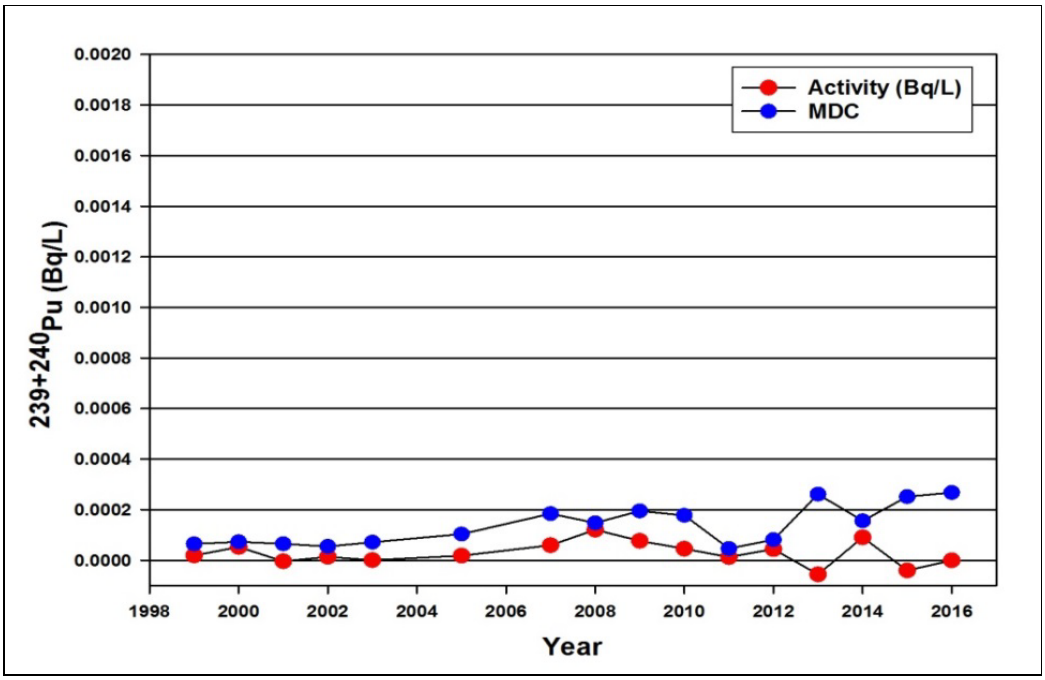


Figure 5-5: $^{239+240}$Pu in Hobbs Drinking Water from 1999 – 2016

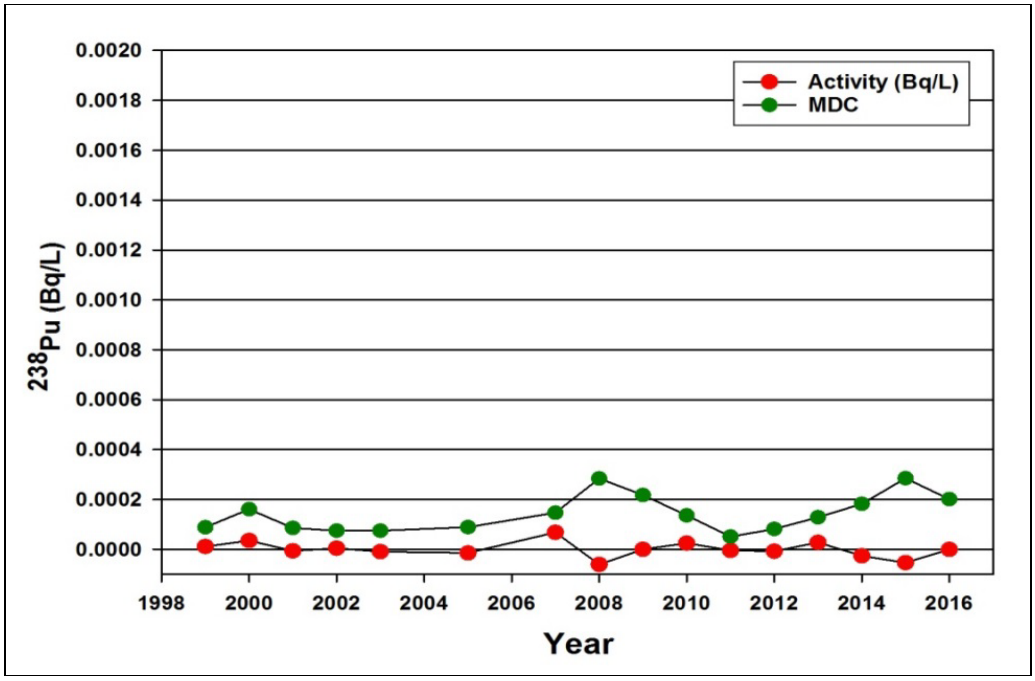


Figure 5-6: ^{238}Pu in Hobbs Drinking Water from 1999 – 2016

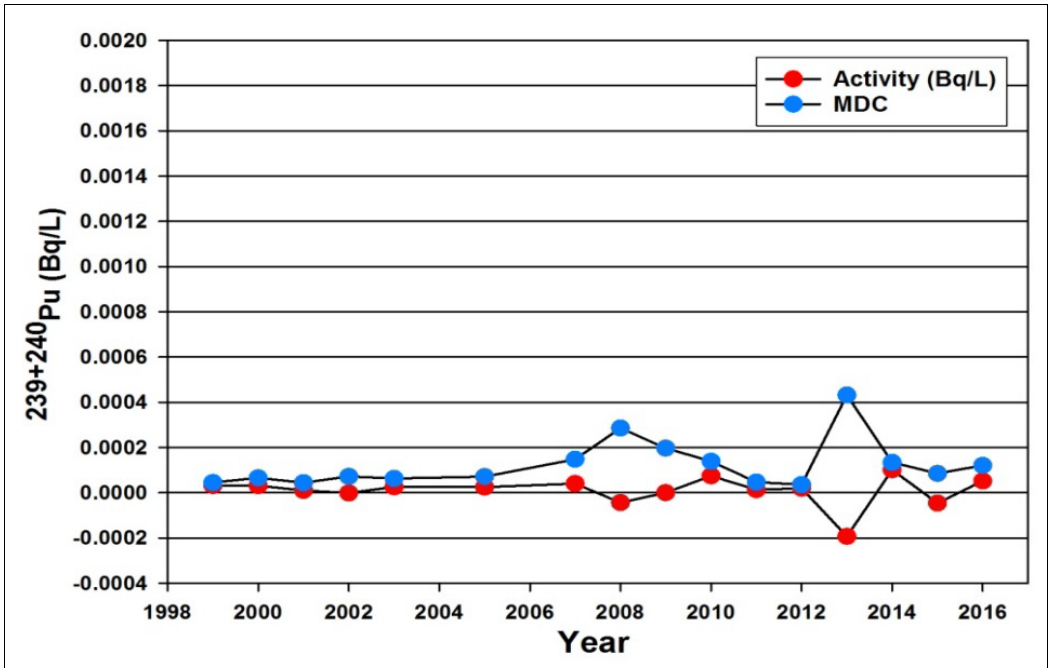


Figure 5-7: $^{239+240}$Pu in Double Eagle Drinking Water from 1999 -2016

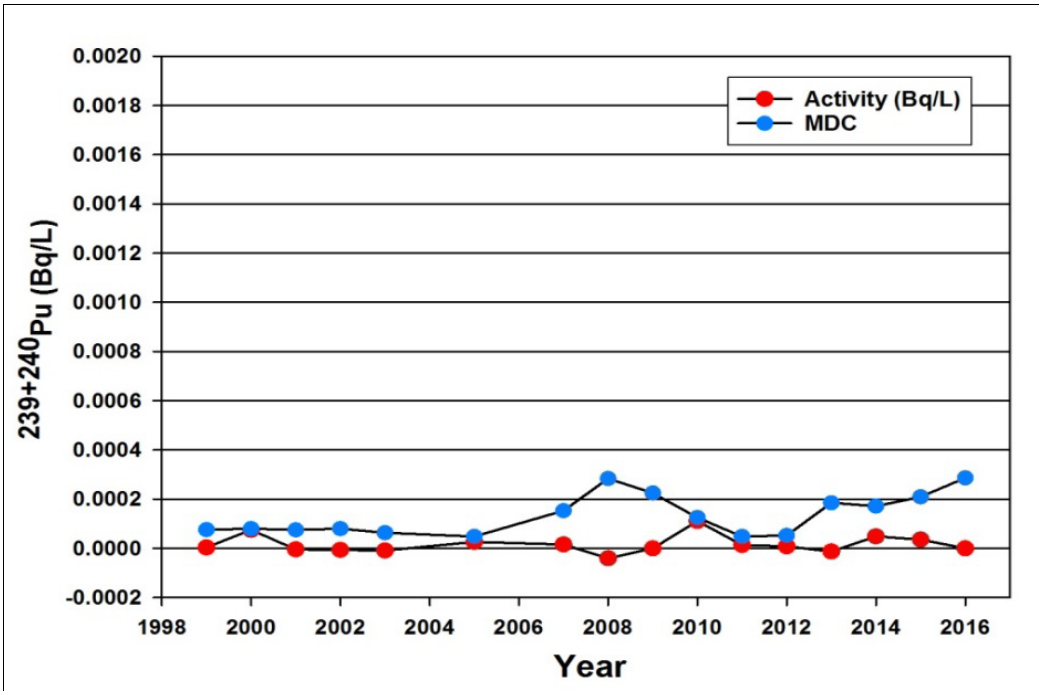


Figure 5-8: $^{239+240}$Pu in Loving Drinking Water from 1999 – 2016

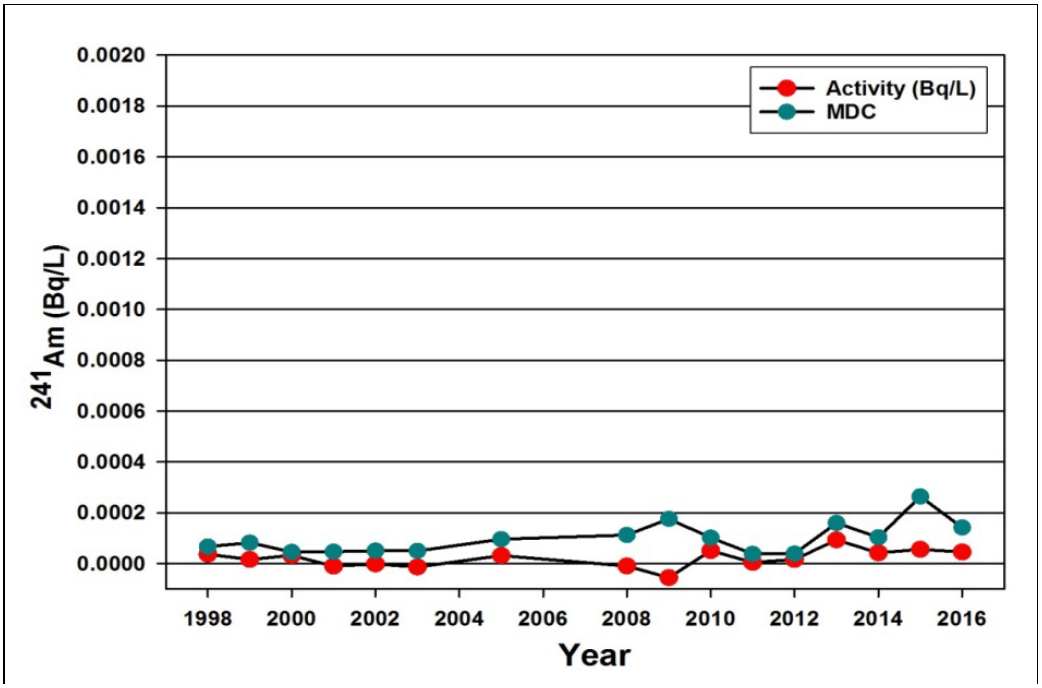


Figure 5-9: ^{241}Am in Otis Drinking Water from 1998 - 2016

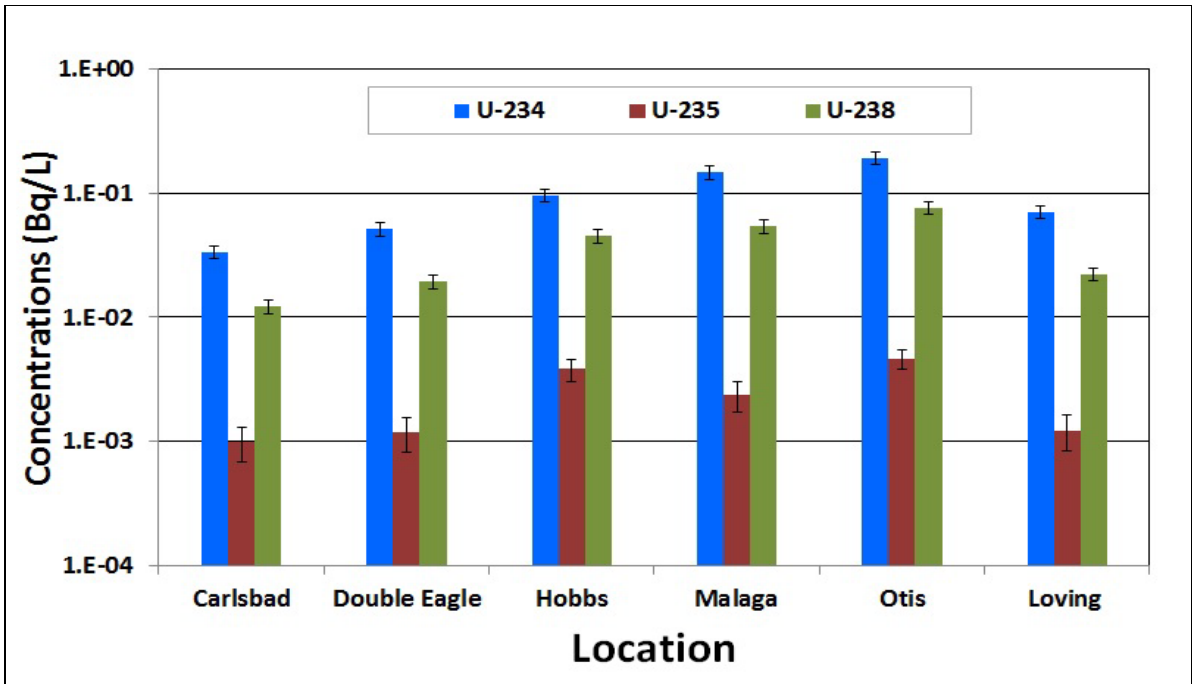


Figure 5-10: The ^{234}U, ^{235}U, and ^{238}U concentrations (Bq/L) in Regional Drinking Water in 2016

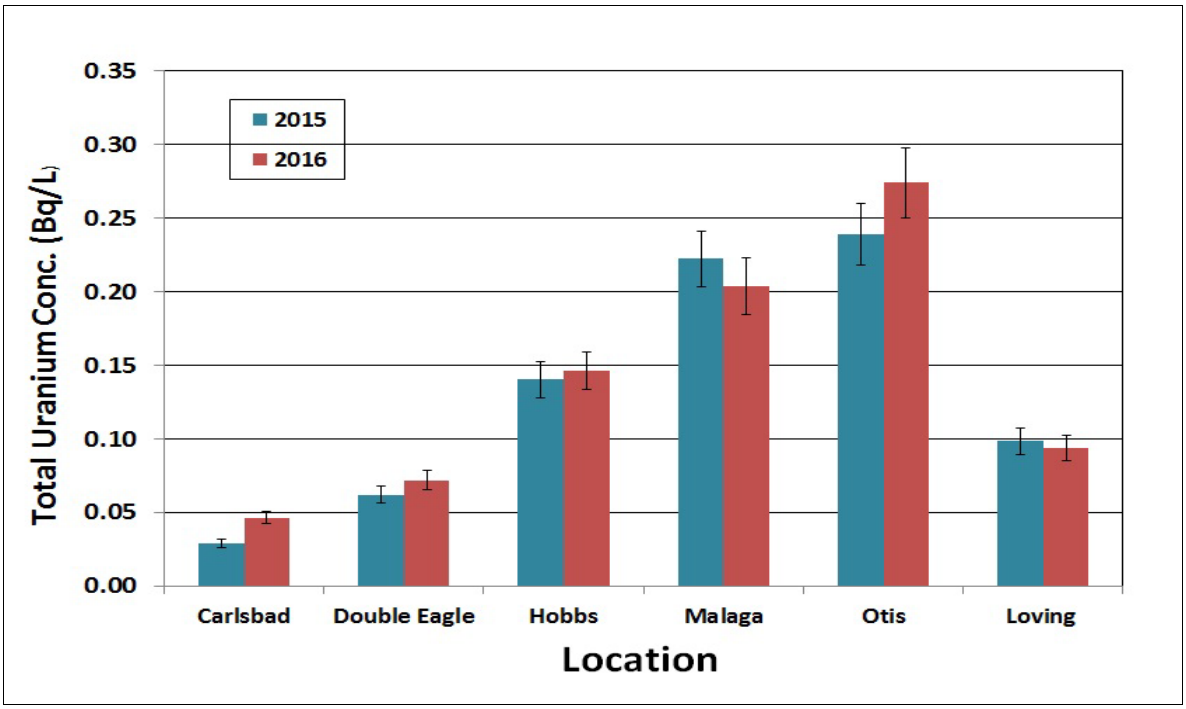


Figure 5-11: Total Uranium Concentrations in Bq/L in Regional Drinking Water collected in 2016

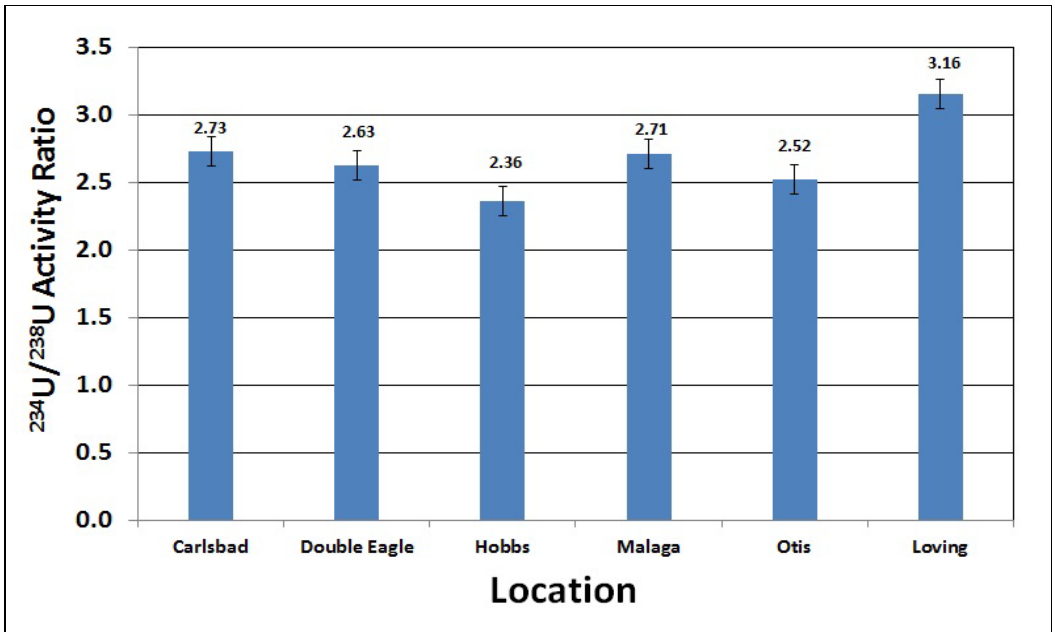


Figure 5-12: $^{234}U/^{238}U$ Activity Ratio in Regional Drinking Water During 2016

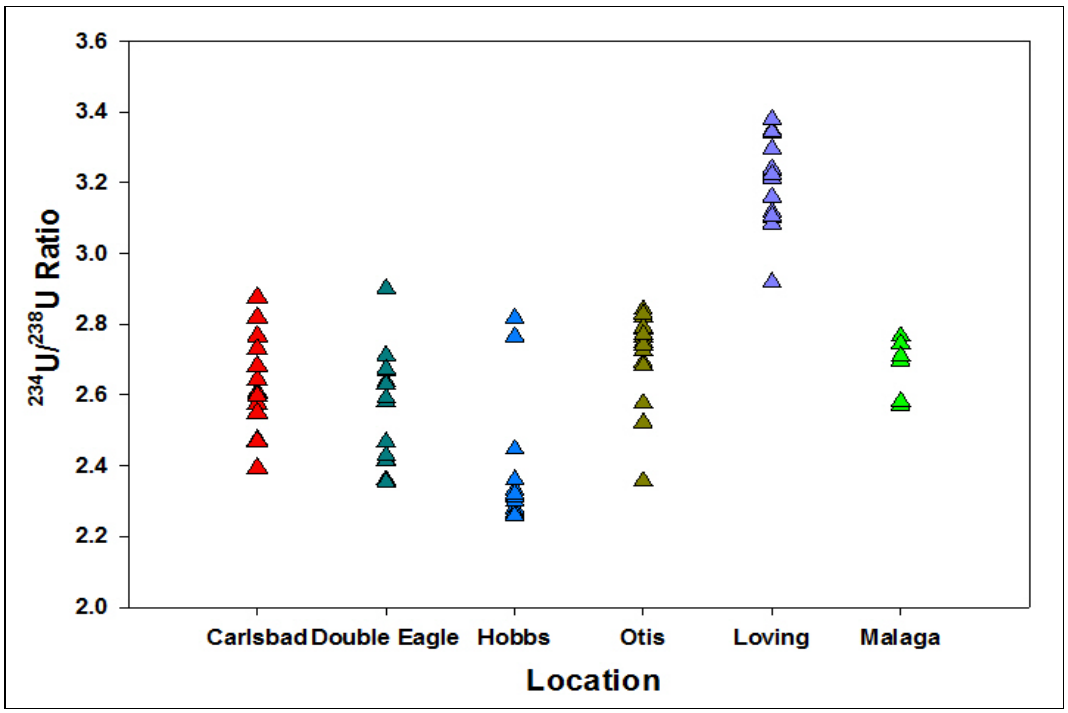


Figure 5-13: Variation in $^{234}U/^{238}U$ Activity Ratio in Regional Drinking Water from 1998 – 2016

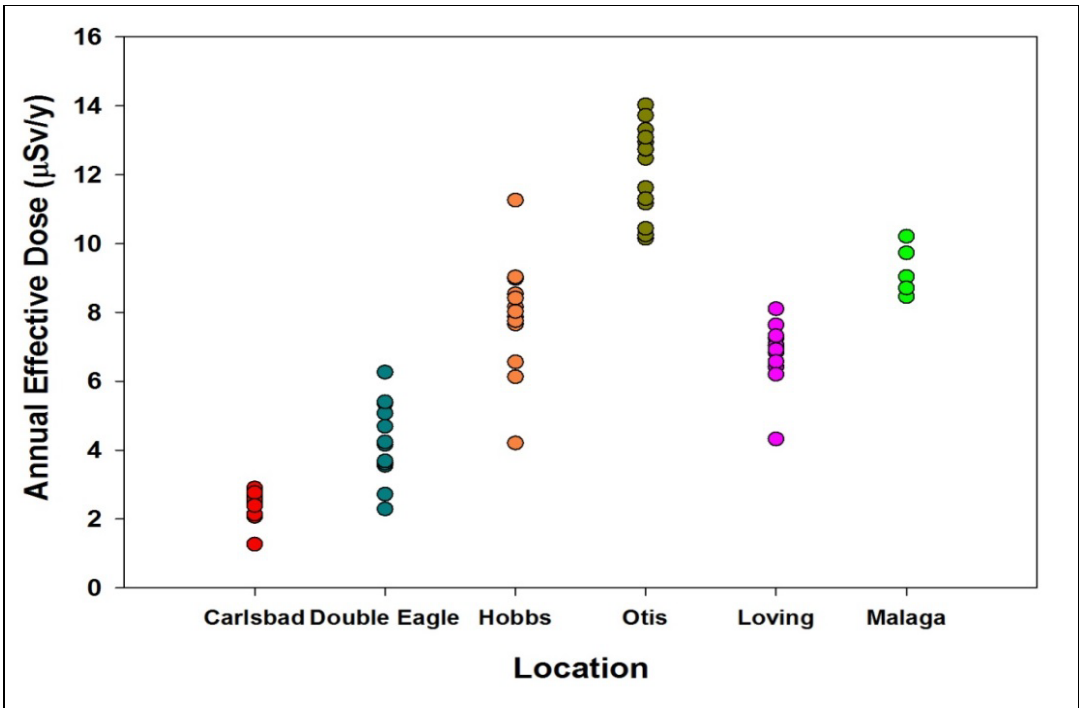


Figure 5-14: Annual Effective Dose (µSv/y) Due to Ingestion of Uranium in Drinking Water in the Vicinity of the WIPP Site

Table 5-5: Variability of Natural Uranium Concentrations in the Drinking Water Around the World

Country	Uranium Conc. (mBq/L)	Reference
Ontario, Canada	1.24-104.5	OMEE, 1996
Jordan	0.996-348.3	Gedeon, et al., 1994
Kuwait	0.498-62.19	Bou-Rabee, 1995
South Greenland	12.4-24.9	Brown et al., 1983
Turkey	4.98-437.9	Kumru, 1995
China	0.0996-696.6	UNSCEAR, 2008,
Iran	24.9-271.2	Alirezazadeh and Garshasbi, 2003
Norway	<0.498-4229	Banks et al., 1995
Sweden	< 4.98-11,693	Selden et al., 2000
Argentina	0.5-5000	UNSCEAR, 2008
Brazil	0.4-400	Geraldo et al., 1979
China	0.09-950	UNSCEAR, 2008
Czech Republic	3-1100	UNSCEAR, 2008
Finland	0.8-120,000	UNSCEAR, 2008
France	8-1000	UNSCEAR, 2008

Table 5-5: Variability of Natural Uranium Concentrations in the Drinking Water Around the World (continued)

Country	Uranium Conc. (mBq/L)	Reference
Germany	0.5-900	UNSCEAR, 2008
Greece	0.2-30	UNSCEAR, 2008
Hungary	1-1000	UNSCEAR, 2008
India	0.09-2	UNSCEAR, 2008
Italy	0.3-400	UNSCEAR, 2008
Morocco	0.8-700	UNSCEAR, 2008
Romania	0.6-90	UNSCEAR, 2008
Spain	0.05-9	UNSCEAR, 2008
Switzerland	8-800	UNSCEAR, 2008
United States	0.5-90	Cothern and Lappenbusch, 1983
Poland	1.0-56	Kozlowska et al., 2007
Austria	2.5-2226	Gegner and Irweck, 2005

Table 5-6: Comparison of Activity Concentration Ratios of $^{234}U/^{238}U$ and $^{235}U/^{238}U$ in water samples collected near the WIPP Site with Other Countries

Source of water sample	Type of water	$^{234}U/^{238}U$	$^{235}U/^{238}U$	Reference
Carlsbad	Drinking water	2.73	0.081	Present work
Double Eagle	Drinking water	2.63	0.061	Present work
Hobbs	Drinking water	2.36	0.056	Present work
Otis	Drinking water	2.52	0.061	Present work
Loving	Drinking water	3.16	0.055	Present work
Malaga	Drinking water	2.71	0.044	Present work
UK	Water	1.0-3.0	-	Gilkeson et al.
Poland	Mineral water	0.82-1.12	-	Nguyen et al.
India	Sea water	1.11-1.14	0.045-0.047	Joshi et al.
Ghana, Obuasi	Ground water	1.07-1.44	0.042-0.045	Awudu et al.
Ghana, Obuasi	Surface water	1.06-1.76	0.044-0.045	Awudu et al.
Ghana, Obuasi	Tap water	1.06-1.73	0.044-0.045	Awudu et al.
INL, Idaho	Ground water	1.5-3.1	-	Roback et al.
Tunisia	Mineral water	1.16-2.46	-	Gharbi et al.

Table 5-7: Historical Activity Concentrations of ^{234}U, ^{235}U and ^{238}U (Bq/L) Measured in Carlsbad Drinking Water

Year	^{234}U (Bq/L)	^{235}U (Bq/L)	^{238}U (Bq/L)
1998	3.34E-02	7.52E-04	1.35E-02
1999	2.94E-02	6.99E-04	1.14E-02
2000	2.81E-02	8.12E-04	1.08E-02
2001	3.15E-02	9.68E-04	1.21E-02
2002	3.02E-02	7.97E-04	1.26E-02
2003	2.90E-02	5.52E-04	1.05E-02
2005	2.75E-02	1.54E-03	1.11E-02
2007	NR	NR	NR
2008	7.73E-02	3.09E-03	3.18E-02
2009	2.48E-02	3.57E-04	9.24E-03
2010	2.99E-02	5.64E-04	1.17E-02
2011	2.83E-02	7.83E-03	1.09E-02
2012	9.20E-03	1.85E-04	3.26E-03
2013	2.47E-02	3.80E-04	9.35E-03
2014	2.85E-02	5.83E-04	1.06E-02
2015	2.09E-02	3.39E-04	7.80E-03
2016	3.34E-02	9.90E-04	1.23E-02

NR = not reported

Table 5-8: Historical Activity Concentrations of ^{234}U, ^{235}U and ^{238}U (Bq/L) Measured in Double Eagle Drinking Water

Year	^{234}U (Bq/L)	^{235}U (Bq/L)	^{238}U(Bq/L)
1998	NR	NR	NR
1999	6.19E-02	1.35E-04	2.32E-02
2000	5.40E-02	1.38E-04	2.19E-02
2001	4.10E-02	1.22E-04	1.74E-02
2002	4.16E-02	1.01E-04	1.77E-02
2003	4.25E-02	8.89E-05	1.61E-02
2005	5.83E-02	1.43E-04	2.48E-02
2007	NR	NR	NR
2008	1.86E-01	4.31E-04	7.94E-02
2009	6.97E-02	7.55E-04	2.89E-02
2010	4.89E-02	1.36E-04	2.01E-02
2011	4.80E-02	8.45E-05	1.86E-02
2012	8.75E-03	3.55E-04	3.22E-03
2013	4.69E-02	4.90E-03	1.81E-02
2014	4.94E-02	6.12E-04	1.85E-02
2015	4.55E-02	9.19E-04	1.57E-02
2016	5.14E-02	1.19E-03	1.96E-02

NR = not reported

Table 5-9: Historical Activity Concentrations of ^{234}U, ^{235}U and ^{238}U (Bq/L) Measured in Hobbs Drinking Water

Year	^{234}U (Bq/L)	^{235}U (Bq/L)	^{238}U (Bq/L)
1998	NR	NR	NR
1999	8.81E-02	2.46E-03	3.86E-02
2000	9.06E-02	2.34E-03	3.99E-02
2001	7.52E-02	2.59E-03	3.32E-02
2002	9.40E-02	2.37E-03	4.05E-02
2003	1.30E-01	2.51E-03	4.61E-02
2005	9.82E-02	2.68E-03	4.27E-02
2007	NR	NR	NR
2008	2.87E-01	1.18E-02	1.31E-01
2009	8.94E-02	1.99E-03	3.86E-02
2010	1.04E-01	2.23E-03	4.59E-02
2011	1.04E-01	2.60E-03	4.50E-02
2012	1.61E-02	4.31E-04	5.82E-03
2013	9.25E-02	2.18E-03	3.97E-02
2014	9.82E-02	1.89E-03	4.01E-02
2015	9.67E-02	2.17E-03	4.17E-02
2016	1.05E-01	2.48E-03	4.44E-02

NR = not reported

Table 5-10: Historical Activity Concentrations of ^{234}U, ^{235}U and ^{238}U (Bq/L) Measured in Otis Drinking Water

Year	^{234}U (Bq/L)	^{235}U (Bq/L)	^{238}U (Bq/L)
1998	1.29E-01	2.73E-03	4.67E-02
1999	1.50E-01	2.85E-03	5.30E-02
2000	1.44E-01	2.97E-03	5.16E-02
2001	1.62E-01	3.30E-03	6.01E-02
2002	1.47E-01	3.34E-03	5.34E-02
2003	1.34E-01	2.56E-03	4.81E-02
2005	1.17E-01	2.60E-03	4.36E-02
2007	NR	NR	NR
2008	3.89E-01	1.35E-02	1.53E-01
2009	1.47E-01	3.80E-03	5.35E-02
2010	1.54E-01	2.66E-03	5.41E-02
2011	1.54E-01	1.19E-02	2.39E-01
2012	3.94E-02	1.00E-03	1.39E-02
2013	1.51E-01	3.17E-03	5.45E-02
2014	1.71E-01	3.46E-03	7.24E-02
2015	1.70E-01	2.95E-03	6.61E-02
2016	2.70E-02	1.44E-03	1.13E-02

NR = not reported

Table 5-11: Historical Activity Concentrations of ^{234}U, ^{235}U and ^{238}U (Bq/L) Measured in Loving Drinking Water

Year	^{234}U (Bq/L)	^{235}U (Bq/L)	^{238}U (Bq/L)
1998	NR	NR	NR
1999	8.15E-02	1.66E-03	2.63E-02
2000	8.38E-02	1.63E-03	2.59E-02
2001	8.05E-02	1.61E-03	2.48E-02
2002	8.82E-02	1.63E-03	2.83E-02
2003	7.91E-02	1.35E-03	2.40E-02
2005	8.13E-02	1.42E-03	2.64E-02
2007	NR	NR	NR
2008	2.56E-01	5.15E-03	7.71E-02
2009	7.42E-02	1.26E-03	2.22E-02
2010	8.00E-02	1.20E-03	2.49E-02
2011	7.50E-02	3.90E-02	2.57E-02
2012	2.53E-02	4.93E-04	7.58E-03
2013	7.17E-02	1.20E-03	2.31E-02
2014	7.57E-02	1.63E-03	2.24E-02
2015	7.42E-02	1.26E-03	2.30E-02
2016	7.05E-02	1.23E-03	2.23E-02

NR = not reported

Table 5-12: Historical Activity Concentrations of ^{234}U, ^{235}U and ^{238}U (Bq/L) Measured in Malaga Drinking Water

Year	^{234}U (Bq/L)	^{235}U (Bq/L)	^{238}U (Bq/L)
2011	1.38E-01	2.56E-03	5.34E-02
2012	1.33E-01	1.92E-03	4.83E-02
2013	1.40E-01	3.33E-03	5.46E-02
2014	1.67E-01	4.59E-03	6.19E-02
2015	1.57E-01	4.99E-03	6.07E-02
2016	1.47E-01	2.36E-03	5.43E-02

*Collection started in 2011

Table 5-13: Gamma Emitting Radionuclides Measured in Drinking Water in 2016

Radionuclide	Location	Activity Bq/L	Unc(2-sig) (Bq/L)	MDC (Bq/L)	Status
^{137}Cs	Carlsbad	3.36E-02	2.87E-02	9.43E-02	Not Detected
	Otis	4.40E-03	2.88E-02	9.56E-02	Not Detected
	Loving	4.82E-02	2.88E-02	9.47E-02	Not Detected
	Hobbs	3.48E-02	2.75E-02	9.07E-02	Not Detected
	Hobbs (Dup)	1.05E-02	2.87E-02	9.51E-02	Not Detected
	Double Eagle	3.73E-03	2.88E-02	9.55E-02	Not Detected
	Malaga	2.47E-02	2.88E-02	9.51E-02	Not Detected
	Blank	2.65E-02	2.85E-02	9.42E-02	Not Detected
^{60}Co	Carlsbad	1.19E-02	2.69E-02	8.92E-02	Not Detected
	Otis	1.91E-02	2.61E-02	8.65E-02	Not Detected
	Loving	1.30E-03	2.67E-02	8.88E-02	Not Detected
	Hobbs	1.81E-02	2.58E-02	8.55E-02	Not Detected
	Hobbs (Dup)	2.94E-02	2.64E-02	8.72E-02	Not Detected
	Double Eagle	1.03E-02	2.65E-02	8.80E-02	Not Detected
	Malaga	2.45E-02	2.61E-02	8.64E-02	Not Detected
	Blank	4.40E-02	2.59E-02	8.50E-02	Not Detected
^{40}K	Carlsbad	-1.25E-01	3.47E-01	1.16E+00	Not Detected
	Otis	5.21E-01	3.34E-01	1.10E+00	Not Detected
	Loving	-4.41E-01	3.52E-01	1.18E+00	Not Detected
	Hobbs	3.71E-02	3.31E-01	1.10E+00	Not Detected
	Hobbs (Dup)	4.35E-02	3.39E-01	1.13E+00	Not Detected
	Double Eagle	3.56E-01	3.37E-01	1.11E+00	Not Detected
	Malaga	-1.67E-01	3.42E-01	1.14E+00	Not Detected
	Blank	-2.65E-01	3.38E-01	1.13E+00	Not Detected

Non-Radiological Monitoring Results

Samples collected by the CEMRC from each location were analyzed for Inorganics, consisting of elemental analyses, anion analyses, and analysis for mercury. Each analysis was performed separately. Current methods used for the various analyses performed on each samples are summarized in Table 6.1. Present results, as well as the results of previous analyses for drinking water, are consistent for each source across sampling periods, and are below levels specified under the EPA Safe Drinking Water Act (U.S. EPA: 2012). Previous results published by the CEMRC can be found on the CEMRC website (www.cemrc.org). General information about inorganic contaminants in drinking water is listed in Table 5-2. The 2016 monitoring results show

no increase in the levels of inorganics that could be attributed to WIPP-related activities or the February 2014 WIPP underground radiation release event.

The CEMRC has the ability to analyze drinking water samples for seven different inorganic anions and over 30 different inorganic metals. The 2016 metal results and how they compare to past results are summarized in Tables 5-14 through 5-19 for the six regional drinking water sources. The results exhibited in these tables are not used in assessing regulatory compliance; however, the CEMRC results for drinking water from the Carlsbad (Sheep Draw) and WIPP (Double Eagle) locations generally agree with the measurements for the same elements published by the City of Carlsbad every year (http://cityofcarlsbadnm.com/CCR%202016.pdf).

Figures 5-15 through 5-22 compare the history of the following selected elements measured in drinking water collected from the surrounding areas of WIPP: Arsenic (As), Lead (Pb), Antimony (Sb), and Uranium (U) and Barium (Ba), Chromium (Cr) and Copper (Cu),. As mentioned earlier, drinking water sampling did not take place during the 2004 and 2006 years due to a change in sampling frequency. Since the CEMRC began monitoring inorganic analytes in regional drinking water, the results have exhibited a high level of consistency with past results. Historical data shows that differences of a factor of two or three between one set of successive years is common, as it is for all natural water systems (Conca, et al., 2008).

Minerals are a natural part of all water sources. The amount of inorganic materials in drinking water is determined primarily by local geology and topography, but it can be influenced by urban storm water runoff, industrial or domestic wastewater discharges, oil and gas production, mining, and/or farming, etc. The elemental constituents, As, Ba, Cr, Cu, Pb, Sb, and U are commonly found in the drinking water of the southwest. For example, the city of Midland, TX, has naturally occurring levels of Arsenic, Fluoride, and Selenium in their drinking water (http://www.midlandtexas.gov/ArchiveCenter/ViewFile/Item/152). The drinking water from this part of Texas is supplied from the Ogallala and Dockum formations which are also accessed by the WIPP (Double Eagle) and Hobbs communities. Indeed the concentrations of As measured at the Double Eagle and Hobbs sites are higher than the drinking water for other sampling locations around the WIPP site (most of which have concentrations below the MDC) as shown in Figure 5-16 (Double Eagle) and 5-18 (Hobbs). A comparison of the different sites for select metals is shown in Figure 5-21. However, the levels determined for Double Eagle and Hobbs are still below the EPA limit of 10 µg/L (0.01 mg/L) for As as shown in Table 5-2. (Conca et al., 2008).

The WIPP site is located in the Delaware Basin of New Mexico, the second largest region of the greater Permian Basin. This 600-meter deep salt basin was formed during the Permian Era approximately 250 million years ago when an ancient Sea, once covering the area, evaporated and left behind a nearly impermeable layer of salt. Over time this salt layer was covered by 300 meters of soil and rock (Kerr, 1999; Weeks, 2011). The Permian Basin is now a major source of potassium salts (potash), which are mined from bedded deposits of sylvite and langbeinite (Alto and Fulton, 1965). Sylvite is potassium chloride (KCl) in its natural mineral form while langbeinite is a potassium magnesium sulfate mineral ($K_2Mg_2(SO_4)_3$). Langbeinite ore occurs in

evaporated marine deposits in association with carnallite, halite, and sylvite (Mereiter, 1979; Palache, et al., 1951). Therefore, it is to be expected that through leaching and other natural processes, the water in this region would contain significant quantities of potassium (K), magnesium (Mg) and, of course, sodium (Na). Figure 5-22 summarizes the concentrations of metals in common salts measured in the areas surrounding the WIPP site. Currently there are no EPA regulations for salt-containing components like K, Mg, and Na in drinking water.

By far, the highest concentration of the measured inorganic elements found in the drinking water of this area is Calcium (Ca) for each of the sites sampled around the WIPP (Figure 5-22). This is likely due to the natural limestone deposits found along the edge of the Delaware Basin which once existed as the Capitan Reef during the Permian Era. Limestone is a sedimentary rock composed largely of the minerals calcite and aragonite, which are different crystal forms of calcium carbonate ($CaCO_3$). Limestone leaching creates the stalactites and stalagmites found in the world famous Carlsbad Caverns National Park, located approximately 18 miles southwest of Carlsbad, NM and is a likely source of Calcium (Ca) in the drinking water of the area.

Inorganic anion analysis results are shown separately in Tables 5-21 through 5-26 for the following anions: bromide, chloride, fluoride, nitrate, nitrite, phosphate and sulfate. Drinking water samples have been analyzed for chloride, fluoride, nitrate, phosphate, and sulfate since the CEMRC commenced drinking water analyses in 1998. Only once (at Loving in 2009) has phosphate ever been detected in the drinking water above the MDC while chloride, fluoride, nitrate, and sulfate are routinely detected.

Figures 5-23 through 5-26 are shown for chloride, fluoride, nitrate and sulfate. Just like with inorganic elements, annual measurements for these anions in drinking water show some variation within several orders of magnitude. Chloride has never been detected above the EPA secondary limit of 250 mg/L (250,000 µg/L) for Carlsbad, Double Eagle, Hobbs, and Loving since 1998. However, this anion has frequently been detected above the EPA limit for the Otis and Malaga drinking water (See Figure 5-26). All measurements made from the Malaga site thus far have been detected above the EPA secondary limit, however no baseline is available for the Malaga site for comparison. It should be noted that secondary EPA regulations are not enforceable.

All reported fluoride concentrations are below the EPA limit of 4 mg/L (4,000 µg/L). Due to the high chloride and sulfate concentrations, all drinking water samples must be diluted prior to analysis for anions by IC. This sometimes makes it difficult to detect fluoride anions (which frequently hover just above the MDC). Gaps (such as between 2004 and 2008 for Carlsbad drinking water and after 2008 for Otis drinking water), are often observed when fluoride concentrations fall just below the MDC.

Nitrate is regularly measured in the drinking water at all of the locations around the WIPP site. Loving, Otis, Malaga, and Hobbs water typically have higher nitrate concentrations than Double Eagle and Carlsbad. See Figure 5-25 for nitrate concentrations at all of the sites. All

reported nitrate concentrations are below the EPA limit for nitrate (measured as nitrogen = 10 mg/L or approximately 44,200 µg/L nitrate ion). According to the EPA (2012), common sources of nitrogen (i.e. in the form of nitrites and nitrates) are fertilizer runoff, leaching from septic tanks and sewage, and from erosion of natural deposits.

Like nitrate and chloride, sulfate is another common constituent of drinking water sampled around the WIPP site. Sulfate has never been detected above the EPA secondary limit for the Carlsbad, Double Eagle, Hobbs, and Loving locations (Figure 5-26). On the other hand, sulfate in Malaga and Otis water are routinely above the EPA secondary limit of 250 mg/L (250,000 µg/L). There are no baseline measurements available for the Malaga site. High sulfate concentrations in Otis water have been observed since CEMRC commenced sulfate analyses in 1998 (before the WIPP began accepting mixed waste). Therefore, sulfate concentrations in Otis water cannot be a result of the WIPP activities. It should be noted that secondary EPA regulations are not enforceable. Furthermore, the EPA does not list any potential health effects from long-term exposure to sulfate.

In 2007, bromide and nitrite were added to the list of anions analyzed in drinking water. Therefore a baseline is not available for these two anions. Nitrite has never been detected at any of the sites above the MDC. Bromide has occasionally been detected above the MDC in drinking water collected at Double Eagle, Hobbs, Loving, and Otis, although the observations are few. The EPA (Table 5-2) does not list regulatory information about bromide.

Table 5-14: Measured Concentration of Selected Inorganic Elements in Carlsbad Drinking Water (1998 – 2016)

Carlsbad							
1998-2015					2016		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Ag	13	2	1.75E-02	2.88E-02	1.10E-02	6.29E-04	<MDC
Al	14	7	1.83E+00	4.11E+01	6.40E-01	3.34E-01	3.01E+00
As	16	11	2.97E-01	1.42E+00	2.20E+00	2.70E-01	<MDC
Ba	12	12	6.64E+01	8.19E+01	2.40E-02	1.24E-03	7.32E+01
Be	13	0	N/A	N/A	4.40E-02	3.14E-03	<MDC
Ca	9	9	5.90E+04	7.30E+04	5.53E+02	5.91E+00	7.06E+04
Cd	12	0	N/A	N/A	1.28E-01	-2.12E-02	<MDC
Ce	13	5	5.81E-03	3.42E-02	N/A	N/A	N/A
Co	14	12	8.80E-02	3.41E-01	9.40E-03	5.16E-04	1.30E-01
Cr	15	13	5.14E-01	1.02E+01	2.00E-01	2.96E-02	6.03E+00

Table 5-14: Measured Concentration of Selected Inorganic Elements in Carlsbad Drinking Water (1998 – 2016) (continued)

Carlsbad							
1998-2015					2016		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Cu	14	13	1.30E+00	1.67E+01	3.40E-02	5.91E-03	2.76E+00
Dy	14	1	3.56E-03	3.56E-03	5.40E-03	9.88E-04	<MDC
Er	14	2	3.32E-03	3.38E-03	9.20E-03	9.05E-04	<MDC
Eu	13	10	1.04E-02	2.42E-02	5.60E-03	7.72E-04	2.39E-02
Fe	11	8	7.10E-01	6.52E+02	2.20E+00	-3.32E+00	2.13E+02
Gd	12	3	1.96E-03	3.91E-03	N/A	N/A	N/A
Hg	8	2	2.26E-02	3.14E-02	8.50E-02	7.71E-03	<MDC
K	13	13	1.02E+03	3.56E+03	2.35E+01	-2.04E+01	1.21E+03
La	13	6	5.81E-03	4.42E-02	6.60E-03	9.45E-04	<MDC
Li	11	11	5.14E+00	8.86E+00	2.80E-02	1.93E-02	7.30E+00
Mg	12	12	2.73E+04	3.47E+04	2.90E+00	3.48E-01	3.32E+04
Mn	15	10	5.50E-02	2.93E+01	2.60E-02	4.87E-03	6.97E-01
Mo	11	10	8.93E-01	1.37E+00	3.40E-02	-5.48E-04	1.20E+00
Na	14	14	8.16E+03	4.55E+04	1.30E+01	6.61E-01	2.08E+04
Nd	14	2	8.50E-03	9.35E-03	6.20E-03	6.10E-04	<MDC
Ni	14	13	1.46E+00	3.14E+00	2.00E-02	1.77E-03	2.04E+00
P	8	7	1.61E+01	4.95E+01	2.36E+01	-6.01E+00	3.59E+01
Pb	13	11	1.01E-01	2.07E+00	6.80E-03	1.30E-03	1.64E-01
Pr	14	2	1.93E-03	3.72E-03	N/A	N/A	N/A
Sb	13	8	3.14E-02	1.99E-01	6.80E-03	9.38E-04	2.50E-02
Sc	12	11	1.18E+00	3.03E+00	N/A	N/A	N/A
Se	13	7	-8.83E-02	1.93E+00	2.60E+00	6.63E-01	<MDC
Si	10	10	5.35E+03	6.87E+03	2.46E+01	8.09E-02	6.03E+03
Sr	13	13	2.61E+02	3.62E+02	6.20E-02	5.93E-03	3.43E+02
Th	11	3	6.32E-03	1.76E-02	1.16E-02	1.22E-03	<MDC
Tl	13	13	8.97E-02	1.30E+00	7.80E-03	-2.83E-04	1.23E-01
U	14	14	7.36E-01	1.05E+00	1.24E-02	2.64E-04	9.23E-01
V	15	15	3.07E+00	6.57E+00	5.80E-02	1.83E-02	6.24E+00
Zn	14	13	2.13E+00	1.57E+01	6.40E-01	9.73E-02	4.03E+00

Table 5-15: Measured Concentration of Selected Inorganic Elements in Double Eagle Drinking Water (1998 – 2016)

Double Eagle							
1998-2015					2016		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Ag	15	3	3.62E-03	1.78E-01	2.75E-02	1.47E-04	<MDC
Al	16	10	1.93E+00	7.22E+01	1.60E+00	2.01E-01	1.48E+01
As	15	14	4.48E+00	9.11E+00	5.50E+00	-6.38E-02	<MDC
Ba	13	13	3.82E+01	1.26E+02	6.00E-02	1.62E-03	1.07E+02
Be	14	2	3.63E-02	6.76E-02	1.10E-01	1.16E-02	<MDC
Ca	9	9	4.15E+04	5.94E+04	2.77E+02	-5.58E+00	4.89E+04
Cd	13	1	1.87E-02	1.87E-02	3.20E-01	-5.73E-02	<MDC
Ce	14	3	3.63E-03	3.22E-02	N/A	N/A	N/A
Co	15	12	5.73E-02	1.12E+00	2.35E-02	3.00E-04	1.41E-01
Cr	16	15	8.38E-01	3.25E+01	5.00E-01	5.16E-02	7.32E+00
Cu	15	14	8.09E-01	5.69E+00	8.50E-02	-7.50E-05	4.62E+00
Dy	15	0	N/A	N/A	1.35E-02	1.20E-03	6.15E-02
Er	15	0	N/A	N/A	2.30E-02	8.90E-04	5.79E-02
Eu	14	11	1.68E-02	2.86E-02	1.40E-02	1.18E-03	9.32E-02
Fe	12	10	3.01E-02	9.32E+02	5.50E+00	3.06E+00	1.66E+02
Gd	14	0	N/A	N/A	N/A	N/A	N/A
Hg	7	0	N/A	N/A	8.50E-02	1.52E-02	<MDC
K	14	14	2.22E+03	2.94E+04	1.18E+02	7.01E+00	3.04E+03
La	14	5	1.19E-02	6.26E-02	1.65E-02	8.21E-04	7.50E-02
Li	12	12	9.97E+00	1.95E+01	1.40E-01	6.11E-03	1.97E+01
Mg	12	12	8.51E+03	1.25E+04	1.45E+00	1.91E-01	1.03E+04
Mn	16	13	2.22E-01	6.04E+00	6.50E-02	-3.32E-04	2.87E-01
Mo	12	12	1.42E+00	6.70E+00	8.50E-02	1.05E-03	1.52E+00
Na	15	15	3.84E+03	4.04E+04	6.50E+00	3.85E-01	2.76E+04
Nd	15	1	2.35E-03	2.35E-03	1.55E-02	1.12E-03	4.88E-02
Ni	15	14	7.68E-01	4.03E+00	5.00E-02	-2.17E-04	1.54E+00
P	8	5	6.38E+00	2.35E+01	5.90E+01	4.77E+00	<MDC
Pb	14	13	2.56E-01	5.32E+00	1.70E-02	7.37E-04	9.14E-01
Pr	15	1	9.05E-04	9.05E-04	N/A	N/A	N/A
Sb	14	10	2.41E-02	1.39E-01	1.70E-02	2.14E-03	4.00E-02
Sc	12	11	1.40E+00	6.59E+00	8.00E-01	7.50E-03	3.71E+00
Se	13	10	-4.16E-02	5.30E+00	6.50E+00	-1.08E-01	<MDC
Si	10	10	7.37E+03	1.81E+04	6.15E+01	3.37E+00	1.56E+04
Sr	14	14	5.06E+01	5.82E+02	6.20E-02	2.66E-03	5.64E+02

Table 5-15: Measured Concentration of Selected Inorganic Elements in Double Eagle Drinking Water (1998 – 2016) (continued)

Double Eagle							
1998-2015					2016		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Th	13	4	2.07E-03	8.38E-02	2.90E-02	7.28E-04	6.39E-02
Tl	14	1	-1.23E-02	-1.23E-02	1.95E-02	-1.86E-04	<MDC
U	15	15	1.17E+00	2.38E+00	3.10E-02	1.16E-04	1.63E+00
V	16	16	7.71E+00	4.06E+01	1.45E-01	1.91E-02	3.34E+01
Zn	15	14	1.46E+00	1.25E+01	1.60E+00	1.00E-02	4.69E+00

[1]El = Element analyzed;
[2]N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;
[3]Min = the lowest value measured above MDC; Max = the highest value measured;
[4]MDC = Minimum detectable concentration;
[5]Concentrations below the MDC are reported as <MDC;
N/A = Not Available

Table 5-16: Measured Concentration of Selected Inorganic Elements in Hobbs Drinking Water (1998 – 2016)

Hobbs							
1998-2015					2016		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Ag	15	2	3.86E-03	1.04E-01	2.75E-02	6.29E-04	<MDC
Al	16	13	3.03E+00	1.14E+02	1.60E+00	3.34E-01	8.00E+00
As	15	14	4.55E+00	8.56E+00	5.50E+00	2.70E-01	6.68E+00
Ba	13	13	5.63E+01	6.79E+01	6.00E-02	1.24E-03	5.73E+01
Be	14	1	5.39E-02	5.39E-02	1.10E-01	3.14E-03	<MDC
Ca	9	9	7.63E+04	1.10E+05	1.11E+03	5.91E+00	1.04E+05
Cd	13	0	N/A	N/A	3.20E-01	-2.12E-02	<MDC
Ce	14	10	5.10E-03	3.56E-02	N/A	N/A	N/A
Co	15	13	9.78E-02	3.61E-01	2.35E-02	5.16E-04	2.31E-01
Cr	16	15	6.44E-01	1.13E+01	5.00E-01	2.96E-02	6.21E+00
Cu	15	14	1.06E+00	6.93E+00	8.50E-02	5.91E-03	1.50E+00
Dy	15	1	4.18E-03	4.18E-03	1.35E-02	9.88E-04	<MDC
Er	15	0	N/A	N/A	2.30E-02	9.05E-04	<MDC
Eu	14	10	1.12E-02	1.97E-02	1.40E-02	7.72E-04	<MDC
Fe	12	10	3.64E+01	4.44E+02	5.50E+00	-3.32E+00	2.60E+02
Gd	14	0	N/A	N/A	N/A	N/A	N/A
Hg	7	0	N/A	N/A	8.50E-02	7.71E-03	<MDC

Table 5-16: Measured Concentration of Selected Inorganic Elements in Hobbs Drinking Water (1998 – 2016) (continued)

Hobbs							
1998-2015					2016		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
K	14	14	2.11E+03	2.52E+04	4.70E+01	-2.04E+01	2.48E+03
La	14	5	1.25E-02	5.01E-02	1.65E-02	9.45E-04	<MDC
Li	12	12	2.65E+01	3.89E+01	5.60E-02	1.93E-02	3.89E+01
Mg	12	12	1.90E+04	2.67E+04	1.45E+00	3.48E-01	2.51E+04
Mn	16	15	3.79E-01	3.62E+00	6.50E-02	4.87E-03	2.17E+00
Mo	12	12	2.36E+00	3.31E+00	8.50E-02	-5.48E-04	2.70E+00
Na	15	15	4.97E+03	5.80E+04	2.60E+01	6.61E-01	5.08E+04
Nd	15	5	3.01E-03	1.44E-02	1.55E-02	6.10E-04	<MDC
Ni	15	15	1.67E+00	4.78E+00	5.00E-02	1.77E-03	2.74E+00
P	8	7	1.74E+01	8.31E+01	5.90E+01	-6.01E+00	<MDC
Pb	14	12	9.44E-02	1.19E+00	1.70E-02	1.30E-03	2.11E-01
Pr	15	2	1.57E-03	1.88E-03	N/A	N/A	N/A
Sb	14	10	3.88E-02	8.53E-02	1.70E-02	9.38E-04	6.31E-02
Sc	12	12	3.06E+00	1.05E+01	N/A	N/A	N/A
Se	13	11	-1.70E-01	1.23E+01	6.50E+00	6.63E-01	<MDC
Si	10	10	2.30E+04	2.86E+04	6.15E+01	8.09E-02	2.45E+04
Sr	14	14	7.89E+01	1.14E+03	1.24E-01	5.93E-03	1.22E+03
Th	13	4	2.29E-03	1.36E-01	2.90E-02	1.22E-03	<MDC
Tl	13	2	9.45E-03	2.24E-02	1.95E-02	-2.83E-04	<MDC
U	15	15	2.90E+00	4.30E+00	3.10E-02	2.64E-04	3.85E+00
V	16	16	3.11E+01	3.79E+01	1.45E-01	1.83E-02	3.99E+01
Zn	15	12	8.44E-01	4.37E+00	1.60E+00	9.73E-02	<MDC

[1]El = Element analyzed;
[2]N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;
[3]Min = the lowest value measured above MDC; Max = the highest value measured;
[4]MDC = Minimum detectable concentration;
[5]Concentrations below the MDC are reported as <MDC;
N/A = Not Available

Table 5-17: Measured Concentration of Selected Inorganic Elements in Loving Drinking Water (1998 – 2016)

Loving							
1998-2015					2016		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Ag	15	4	2.55E-03	2.17E-01	1.10E-02	6.29E-04	<MDC
Al	16	11	1.43E+00	3.76E+02	6.40E-01	3.34E-01	5.07E+00
As	15	12	7.89E-01	2.22E+00	2.20E+00	2.70E-01	2.35E+00
Ba	13	13	2.96E+01	3.47E+01	2.40E-02	1.24E-03	3.31E+01
Be	14	1	9.35E-02	9.35E-02	4.40E-02	3.14E-03	<MDC
Ca	9	9	6.71E+04	1.00E+05	5.53E+02	5.91E+00	8.26E+04
Cd	14	0	N/A	N/A	1.28E-01	-2.12E-02	<MDC
Ce	15	6	9.74E-04	2.53E-01	N/A	N/A	N/A
Co	15	13	8.42E-02	4.04E-01	9.40E-03	5.16E-04	1.51E-01
Cr	16	14	1.12E+00	1.12E+01	2.00E-01	2.96E-02	7.90E+00
Cu	15	13	8.06E-01	5.59E+00	3.40E-02	5.91E-03	1.41E+00
Dy	15	0	N/A	N/A	5.40E-03	9.88E-04	<MDC
Er	16	0	N/A	N/A	9.20E-03	9.05E-04	<MDC
Eu	15	10	7.00E-03	1.04E-02	5.60E-03	7.72E-04	1.64E-02
Fe	12	9	3.60E+00	2.57E+02	2.20E+00	-3.32E+00	2.19E+02
Gd	15	2	2.15E-03	1.04E-02	N/A	N/A	N/A
Hg	7	0	N/A	N/A	8.50E-02	7.71E-03	<MDC
K	14	14	1.69E+03	1.98E+04	2.35E+01	-2.04E+01	1.78E+03
La	15	4	6.66E-03	2.22E-02	6.60E-03	9.45E-04	8.18E-03
Li	12	12	1.50E+01	2.24E+01	2.80E-02	1.93E-02	1.99E+01
Mg	12	12	3.02E+04	4.21E+04	2.90E+00	3.48E-01	3.65E+04
Mn	16	10	1.43E-02	1.77E+00	2.60E-02	4.87E-03	1.16E-01
Mo	12	11	1.28E+00	1.72E+00	3.40E-02	-5.48E-04	1.72E+00
Na	15	15	2.33E+03	2.82E+04	2.60E+00	6.61E-01	1.90E+04
Nd	16	2	3.37E-03	7.68E-03	6.20E-03	6.10E-04	<MDC
Ni	15	14	1.41E+00	3.38E+00	2.00E-02	1.77E-03	1.89E+00
P	8	7	2.46E+01	7.32E+01	2.36E+01	-6.01E+00	3.66E+01
Pb	14	10	8.03E-02	1.67E+00	6.80E-03	1.30E-03	1.34E-01
Pr	16	0	N/A	N/A	N/A	N/A	N/A
Sb	14	9	3.43E-02	1.84E-01	6.80E-03	9.38E-04	3.40E-02
Sc	12	11	1.50E+00	4.72E+00	N/A	N/A	N/A
Se	13	6	-2.89E+00	1.53E+00	2.60E+00	6.63E-01	<MDC
Si	10	10	8.91E+03	1.09E+04	2.46E+01	8.09E-02	9.00E+03
Sr	14	14	7.60E+01	9.37E+02	6.20E-02	5.93E-03	7.91E+02

Table 5-17: Measured Concentration of Selected Inorganic Elements in Loving Drinking Water (1998 – 2016) (continued)

Loving							
1998-2015					2016		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Th	14	2	5.69E-03	7.38E-03	1.16E-02	1.22E-03	<MDC
Tl	15	2	2.24E-03	4.32E-02	7.80E-03	-2.83E-04	<MDC
U	15	15	1.90E+00	2.30E+00	1.24E-02	2.64E-04	1.87E+00
V	16	16	1.11E+01	1.61E+01	5.80E-02	1.83E-02	1.58E+01
Zn	15	14	4.79E+00	2.01E+01	6.40E-01	9.73E-02	1.44E+01

[1]El = Element analyzed;
[2]N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;
[3]Min = the lowest value measured above MDC; Max = the highest value measured;
[4]MDC = Minimum detectable concentration;
[5]Concentrations below the MDC are reported as <MDC;
N/A = Not Available

Table 5-18: Measured Concentration of Selected Inorganic Elements in Otis Drinking Water (1998 – 2016)

Otis							
1998-2015					2016		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Ag	13	1	2.63E-02	2.63E-02	5.50E-02	6.29E-04	<MDC
Al	14	5	2.69E+00	1.06E+03	3.20E+00	3.34E-01	9.16E+00
As	15	7	6.53E-01	2.34E+00	1.10E+01	2.70E-01	<MDC
Ba	12	11	1.39E+01	1.97E+01	1.20E-01	1.24E-03	1.26E+01
Be	13	0	N/A	N/A	2.20E-01	3.14E-03	<MDC
Ca	9	9	1.89E+05	3.57E+05	5.53E+03	5.91E+00	3.60E+05
Cd	12	0	N/A	N/A	6.40E-01	-2.12E-02	<MDC
Ce	13	1	2.75E-02	2.75E-02	N/A	N/A	N/A
Co	14	12	2.44E-01	9.51E-01	4.70E-02	5.16E-04	7.48E-01
Cr	15	13	8.12E-01	8.72E+00	1.00E+00	2.96E-02	4.25E+00
Cu	14	13	2.43E+00	6.02E+00	1.70E-01	5.91E-03	5.05E+00
Dy	14	1	3.39E-03	3.39E-03	2.70E-02	9.88E-04	1.17E-01
Er	14	0	N/A	N/A	4.60E-02	9.05E-04	9.99E-02
Eu	13	3	3.42E-03	9.48E-03	2.80E-02	7.72E-04	1.11E-01
Fe	12	11	2.87E+00	1.02E+03	1.10E+01	-3.32E+00	1.07E+03
Gd	13	0	N/A	N/A	N/A	N/A	N/A
Hg	7	1	3.23E-02	3.23E-02	8.50E-02	7.71E-03	<MDC
K	13	13	2.41E+03	4.01E+03	1.18E+02	-2.04E+01	3.12E+03

Table 5-18: Measured Concentration of Selected Inorganic Elements in Otis Drinking Water (1998 – 2016) (continued)

Otis							
1998-2015					2016		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
La	13	2	3.36E-03	6.30E-03	3.30E-02	9.45E-04	1.06E-01
Li	11	11	3.37E+01	6.79E+01	1.40E-01	1.93E-02	5.86E+01
Mg	12	12	5.16E+04	1.08E+05	2.90E+00	3.48E-01	8.79E+04
Mn	14	6	1.98E-01	4.91E+00	1.30E-01	4.87E-03	<MDC
Mo	11	11	2.25E+00	4.68E+00	1.70E-01	-5.48E-04	5.03E+00
Na	13	13	5.35E+04	1.97E+05	1.30E+02	6.61E-01	1.14E+05
Nd	14	3	4.80E-03	3.97E-02	3.10E-02	6.10E-04	9.05E-02
Ni	14	13	2.62E+00	1.11E+01	1.00E-01	1.77E-03	9.32E+00
P	8	8	4.54E+01	3.68E+02	1.18E+02	-6.01E+00	2.26E+02
Pb	13	8	1.08E-01	5.98E-01	3.40E-02	1.30E-03	1.64E-01
Pr	14	0	N/A	N/A	N/A	N/A	N/A
Sb	13	8	3.66E-02	4.10E-01	3.40E-02	9.38E-04	<MDC
Sc	12	10	6.55E-01	5.35E+00	N/A	N/A	N/A
Se	13	6	-2.43E-02	1.19E+00	1.30E+01	6.63E-01	<MDC
Si	10	10	9.30E+03	1.39E+04	1.23E+02	8.09E-02	1.03E+04
Sr	12	12	2.20E+03	4.62E+03	6.20E-01	5.93E-03	4.97E+03
Th	11	3	1.19E-03	5.11E-02	5.80E-02	1.22E-03	1.16E-01
Tl	13	1	-6.30E-03	-6.30E-03	3.90E-02	-2.83E-04	<MDC
U	14	14	3.73E+00	6.06E+00	6.20E-02	2.64E-04	6.10E+00
V	15	14	7.87E+00	1.29E+01	2.90E-01	1.83E-02	1.05E+01
Zn	13	10	1.54E+00	1.16E+01	3.20E+00	9.73E-02	6.83E+00

[1]El = Element analyzed;
[2]N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;
[3]Min = the lowest value measured above MDC; Max = the highest value measured;
[4]MDC = Minimum detectable concentration;
[5]Concentrations below the MDC are reported as <MDC;
N/A = Not Available

Table 5-19: Measured Concentration of Selected Inorganic Elements in Malaga Drinking Water (2011 – 2016)

Malaga							
2011-2015					2016		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Ag	5	0	N/A	N/A	5.50E-02	6.29E-04	<MDC
Al	5	2	2.39E+00	2.66E+00	3.20E+00	3.34E-01	3.99E+00
As	5	1	5.44E+00	5.44E+00	1.10E+01	2.70E-01	<MDC
Ba	5	5	1.44E+01	1.66E+01	1.20E-01	1.24E-03	1.45E+01
Be	5	1	3.04E-01	3.04E-01	2.20E-01	3.14E-03	<MDC
Ca	5	5	2.41E+05	3.51E+05	5.53E+03	5.91E+00	3.33E+05
Cd	5	0	N/A	N/A	6.40E-01	-2.12E-02	<MDC
Ce	5	0	N/A	N/A	N/A	N/A	N/A
Co	5	5	3.39E-01	8.57E-01	4.70E-02	5.16E-04	5.53E-01
Cr	5	5	5.80E-01	1.00E+01	1.00E+00	2.96E-02	4.45E+00
Cu	5	4	1.57E+00	3.66E+00	1.70E-01	5.91E-03	2.33E+00
Dy	5	0	N/A	N/A	2.70E-02	9.88E-04	<MDC
Er	5	0	N/A	N/A	4.60E-02	9.05E-04	<MDC
Eu	5	0	N/A	N/A	2.80E-02	7.72E-04	<MDC
Fe	5	5	5.90E+02	1.02E+03	1.10E+01	-3.32E+00	1.33E+03
Gd	5	0	N/A	N/A	N/A	N/A	N/A
Hg	5	0	N/A	N/A	8.50E-02	7.71E-03	<MDC
K	5	5	2.57E+03	3.38E+03	1.18E+02	-2.04E+01	3.27E+03
La	5	0	N/A	N/A	3.30E-02	9.45E-04	<MDC
Li	4	4	3.72E+01	5.40E+01	1.40E-01	1.93E-02	5.48E+01
Mg	5	5	6.98E+04	9.90E+04	2.90E+01	3.48E-01	1.07E+05
Mn	5	2	2.84E-01	8.34E-01	1.30E-01	4.87E-03	4.59E-01
Mo	4	4	3.23E+00	3.99E+00	1.70E-01	-5.48E-04	3.94E+00
Na	5	5	7.53E+04	1.11E+05	1.30E+02	6.61E-01	1.08E+05
Nd	5	0	N/A	N/A	3.10E-02	6.10E-04	<MDC
Ni	5	5	5.66E+00	1.06E+01	1.00E-01	1.77E-03	8.76E+00
P	5	5	5.64E+01	4.45E+02	1.18E+02	-6.01E+00	2.20E+02
Pb	5	4	1.46E-01	1.75E+00	3.40E-02	1.30E-03	2.01E+00
Pr	5	0	N/A	N/A	N/A	N/A	N/A
Sb	5	2	3.95E-02	6.38E-02	3.40E-02	9.38E-04	<MDC
Sc	4	4	1.54E+00	2.41E+00	N/A	N/A	N/A
Se	5	1	1.65E+01	1.65E+01	1.30E+01	6.63E-01	<MDC
Si	5	5	9.12E+03	1.04E+04	1.23E+02	8.09E-02	9.82E+03
Sr	5	5	3.71E+03	4.13E+03	6.20E-01	5.93E-03	4.57E+03
Th	4	0	N/A	N/A	5.80E-02	1.22E-03	<MDC
Tl	5	0	N/A	N/A	3.90E-02	-2.83E-04	<MDC
U	5	5	4.38E+00	5.61E+00	6.20E-02	2.64E-04	4.81E+00
V	5	5	8.30E+00	1.20E+01	2.90E-01	1.83E-02	1.11E+01
Zn	5	5	1.52E+01	4.64E+01	3.20E+00	9.73E-02	3.72E+01

[1]El = Element analyzed;
[2]N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;
[3]Min = the lowest value measured above MDC; Max = the highest value measured;
[4]MDC = Minimum detectable concentration;
[5]Concentrations below the MDC are reported as <MDC;
N/A = Not Available

Table 5-20: Measured Concentration of Select Anions in Carlsbad Drinking Water (1998 – 2016)

Carlsbad							
1998-2015					2016		
Anion[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Bromide	9	1	8.40E+01	8.40E+01	9.90E+00	0.00E+00	<MDC
Chloride	15	14	7.83E+03	7.88E+04	1.50E+00	0.00E+00	3.01E+04
Fluoride	12	11	1.23E+02	8.62E+02	1.70E+00	0.00E+00	3.59E+02
Nitrate	16	16	1.57E+03	5.91E+03	4.40E+00	0.00E+00	4.36E+03
Nitrite	8	0	N/A	N/A	5.00E+00	0.00E+00	<MDC
Phosphate	16	0	N/A	N/A	1.69E+01	0.00E+00	<MDC
Sulfate	15	15	7.61E+04	1.17E+05	6.60E+00	0.00E+00	8.36E+04

[1]El = Element analyzed;
[2]N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;
[3]Min = the lowest value measured above MDC; Max = the highest value measured;
[4]MDC = Minimum detectable concentration;
[5]Concentrations below the MDC are reported as <MDC;
N/A = Not Available

Table 5-21: Measured Concentration of Select Anions in Double Eagle Drinking Water (1998 – 2016)

Double Eagle							
1998-2015					2016		
Anion[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Bromide	9	4	9.49E+01	2.78E+02	9.90E+00	0.00E+00	2.63E+02
Chloride	16	16	2.23E+04	4.59E+04	1.50E+00	0.00E+00	2.94E+04
Fluoride	12	12	4.40E+02	1.36E+03	1.70E+00	0.00E+00	7.25E+02
Nitrate	15	15	6.98E+03	1.46E+04	4.40E+00	0.00E+00	1.26E+04
Nitrite	9	0	N/A	N/A	5.00E+00	0.00E+00	<MDC
Phosphate	16	0	N/A	N/A	1.69E+01	0.00E+00	<MDC
Sulfate	16	16	3.81E+04	5.69E+04	6.60E+00	0.00E+00	3.04E+04

[1]El = Element analyzed;
[2]N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;
[3]Min = the lowest value measured above MDC; Max = the highest value measured;
[4]MDC = Minimum detectable concentration;
[5]Concentrations below the MDC are reported as <MDC;
N/A = Not Available

Table 5-22: Measured Concentration of Select Anions in Hobbs Drinking Water (1998 – 2016)

Hobbs							
1998-2015					2016		
Anion[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Bromide	9	3	8.27E+01	3.94E+02	9.90E+00	0.00E+00	3.65E+02
Chloride	16	16	6.32E+04	1.07E+05	7.50E+00	0.00E+00	9.85E+04
Fluoride	13	13	4.91E+02	2.88E+03	1.70E+00	0.00E+00	1.18E+03
Nitrate	16	16	1.56E+04	2.21E+04	4.40E+00	0.00E+00	2.04E+04
Nitrite	9	0	N/A	N/A	5.00E+00	0.00E+00	<MDC
Phosphate	15	0	N/A	N/A	1.69E+01	0.00E+00	<MDC
Sulfate	16	16	9.60E+04	1.51E+05	3.30E+01	0.00E+00	1.33E+05

Table 5-23: Measured Concentration of Select Anions in Loving Drinking Water (1998 – 2016)

Loving							
1998-2015					2016		
Anion[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Bromide	8	1	3.58E+01	3.58E+01	9.90E+00	0.00E+00	4.40E+01
Chloride	15	15	1.59E+04	3.62E+04	1.50E+00	0.00E+00	2.66E+04
Fluoride	12	9	1.31E+02	2.34E+03	1.70E+00	0.00E+00	4.99E+02
Nitrate	15	15	1.59E+04	2.91E+04	4.40E+00	0.00E+00	2.01E+04
Nitrite	7	0	N/A	N/A	5.00E+00	0.00E+00	<MDC
Phosphate	15	1	5.28E+01	5.28E+01	1.69E+01	0.00E+00	<MDC
Sulfate	14	14	1.18E+05	2.05E+05	3.30E+01	0.00E+00	1.10E+05

Table 5-24: Measured Concentration of Select Anions in Malaga Drinking Water (1998 – 2016)

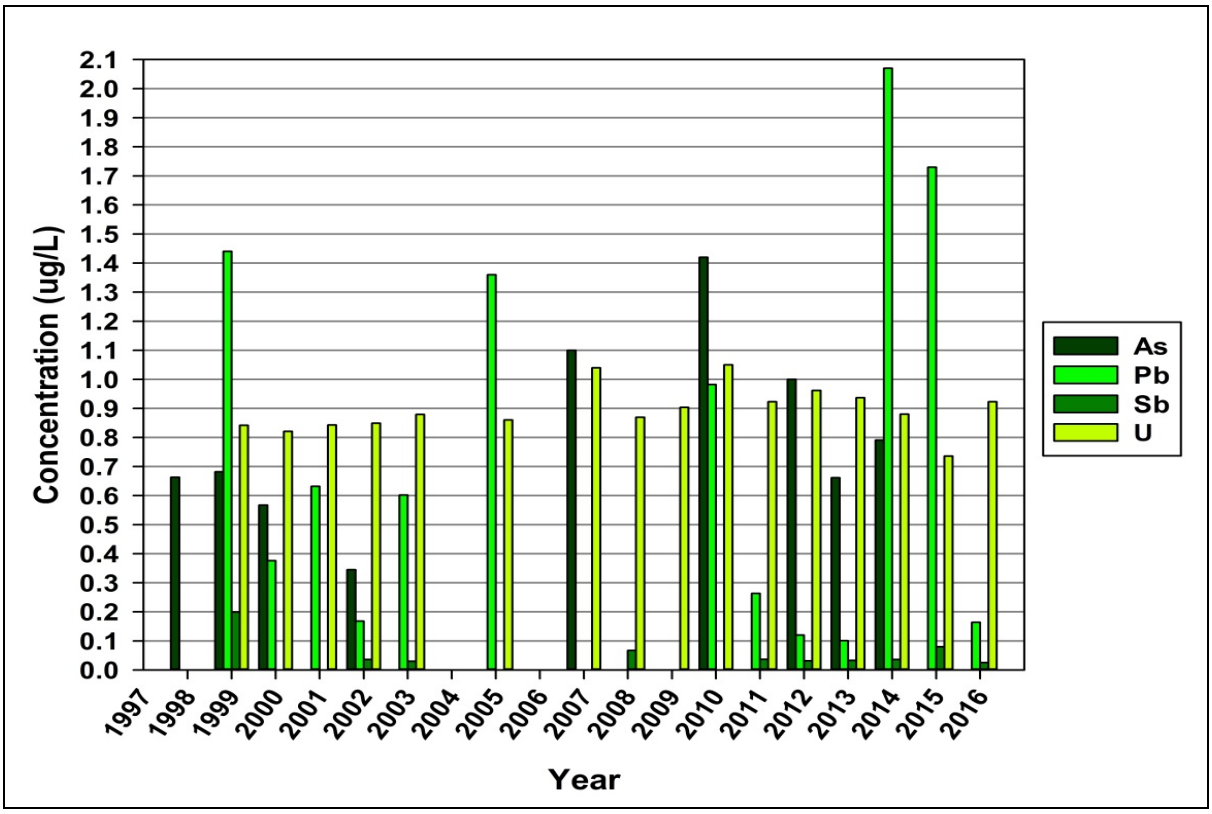
Malaga							
1998-2015					2016		
Anion[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Bromide	5	1	2.40E+02	2.40E+02	4.95E+01	0.00E+00	3.45E+02
Chloride	5	5	3.63E+05	4.30E+05	7.50E+00	0.00E+00	4.17E+05
Fluoride	5	1	8.55E+02	8.55E+02	8.50E+00	0.00E+00	8.15E+02
Nitrate	5	5	1.07E+04	2.41E+04	2.20E+01	0.00E+00	1.64E+04
Nitrite	5	0	N/A	N/A	2.50E+01	0.00E+00	<MDC
Phosphate	5	0	N/A	N/A	8.45E+01	0.00E+00	<MDC
Sulfate	5	5	6.73E+05	7.98E+05	6.60E+01	0.00E+00	7.36E+05

[1]El = Element analyzed;
[2]N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;
[3]Min = the lowest value measured above MDC; Max = the highest value measured;
[4]MDC = Minimum detectable concentration;
[5]Concentrations below the MDC are reported as <MDC;
N/A = Not Available

Table 5-25: Measured Concentration of Select Anions in Otis Drinking Water (1998 – 2016)

Otis							
1998-2015					2016		
Anion[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Bromide	8	2	5.67E+01	3.00E+02	9.90E+01	0.00E+00	3.30E+02
Chloride	15	15	1.26E+05	4.21E+05	1.50E+01	0.00E+00	3.92E+05
Fluoride	13	8	4.70E+02	1.53E+03	1.70E+01	0.00E+00	1.03E+03
Nitrate	16	16	9.59E+03	2.53E+04	4.40E+01	0.00E+00	1.69E+04
Nitrite	8	0	N/A	N/A	5.00E+01	0.00E+00	<MDC
Phosphate	16	0	N/A	N/A	1.69E+02	0.00E+00	<MDC
Sulfate	14	14	3.27E+05	8.94E+05	6.60E+01	0.00E+00	8.09E+05

[1]El = Element analyzed;
[2]N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;
[3]Min = the lowest value measured above MDC; Max = the highest value measured;
[4]MDC = Minimum detectable concentration;
[5]Concentrations below the MDC are reported as <MDC;
N/A = Not Available



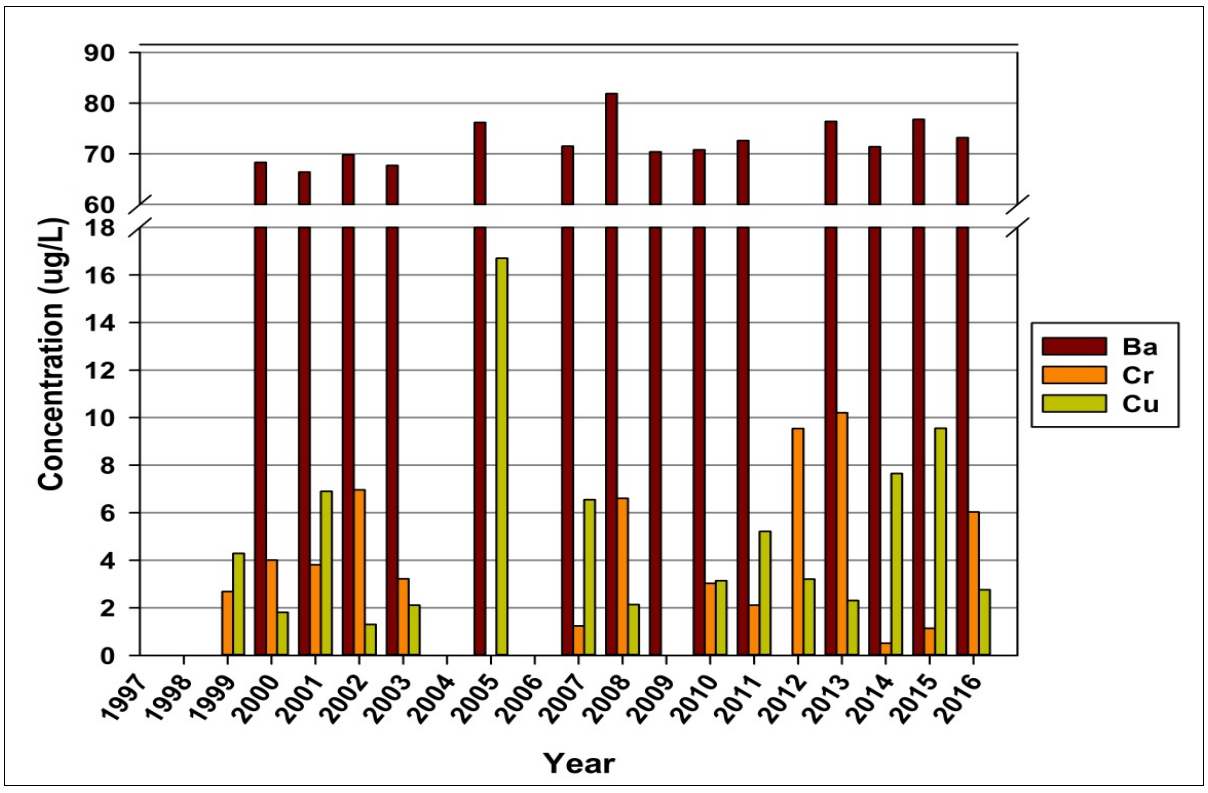
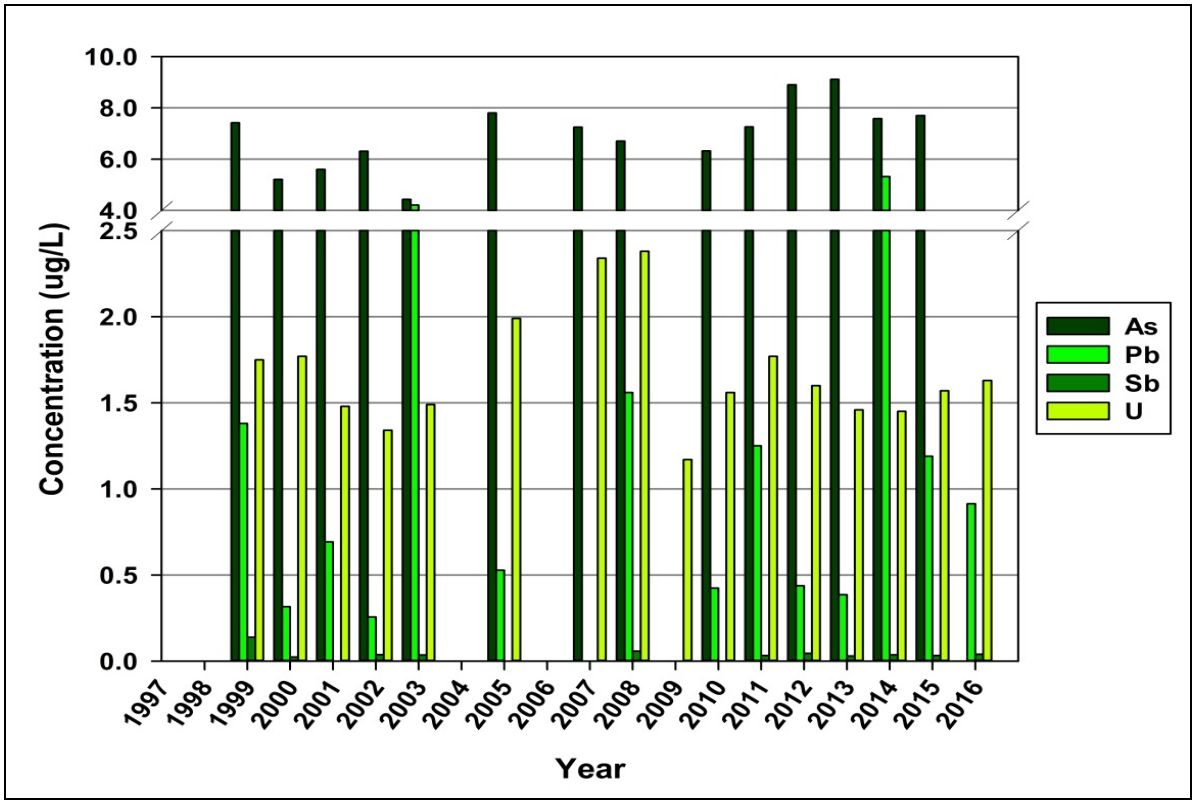


Figure 5-15: Concentrations (µg/L) of Select Inorganic Analytes Measured in Carlsbad Drinking Water (1998 – 2016)



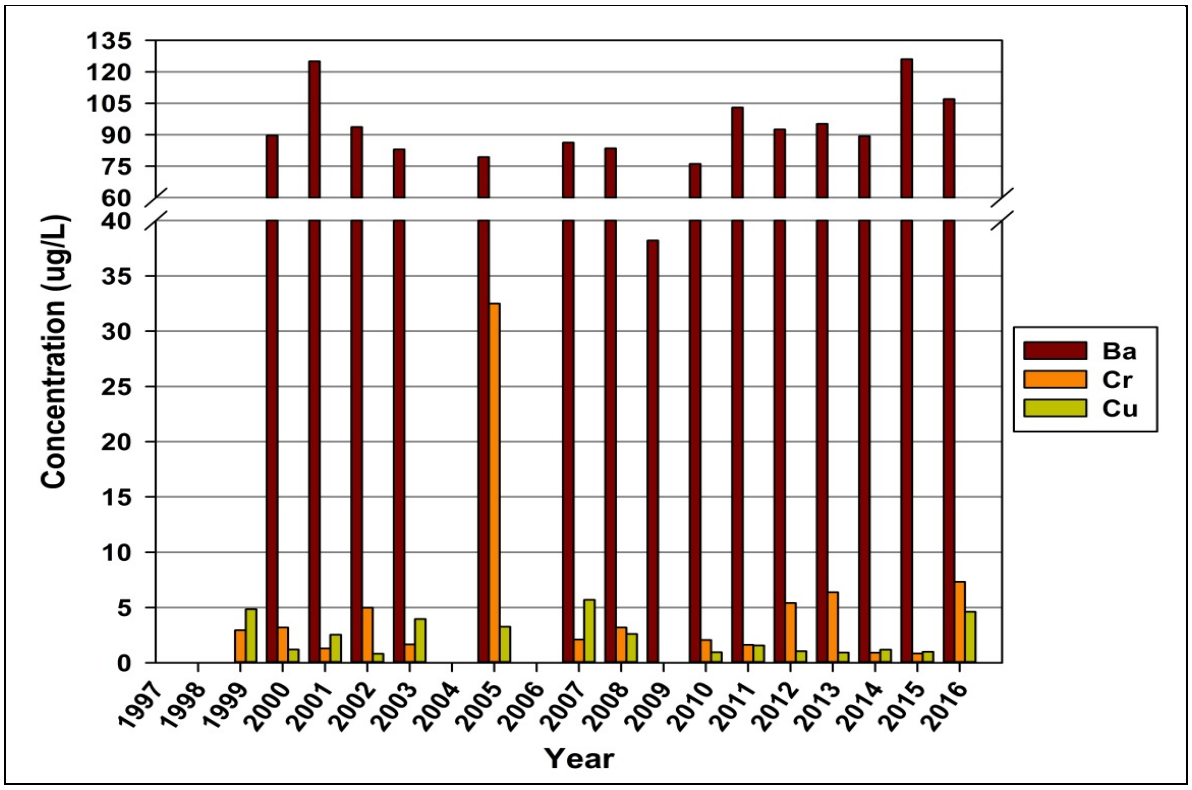


Figure 5-16: Concentrations (µg/L) of Select Inorganic Analytes Measured Near the WIPP site (Double Eagle) (1998 – 2016)

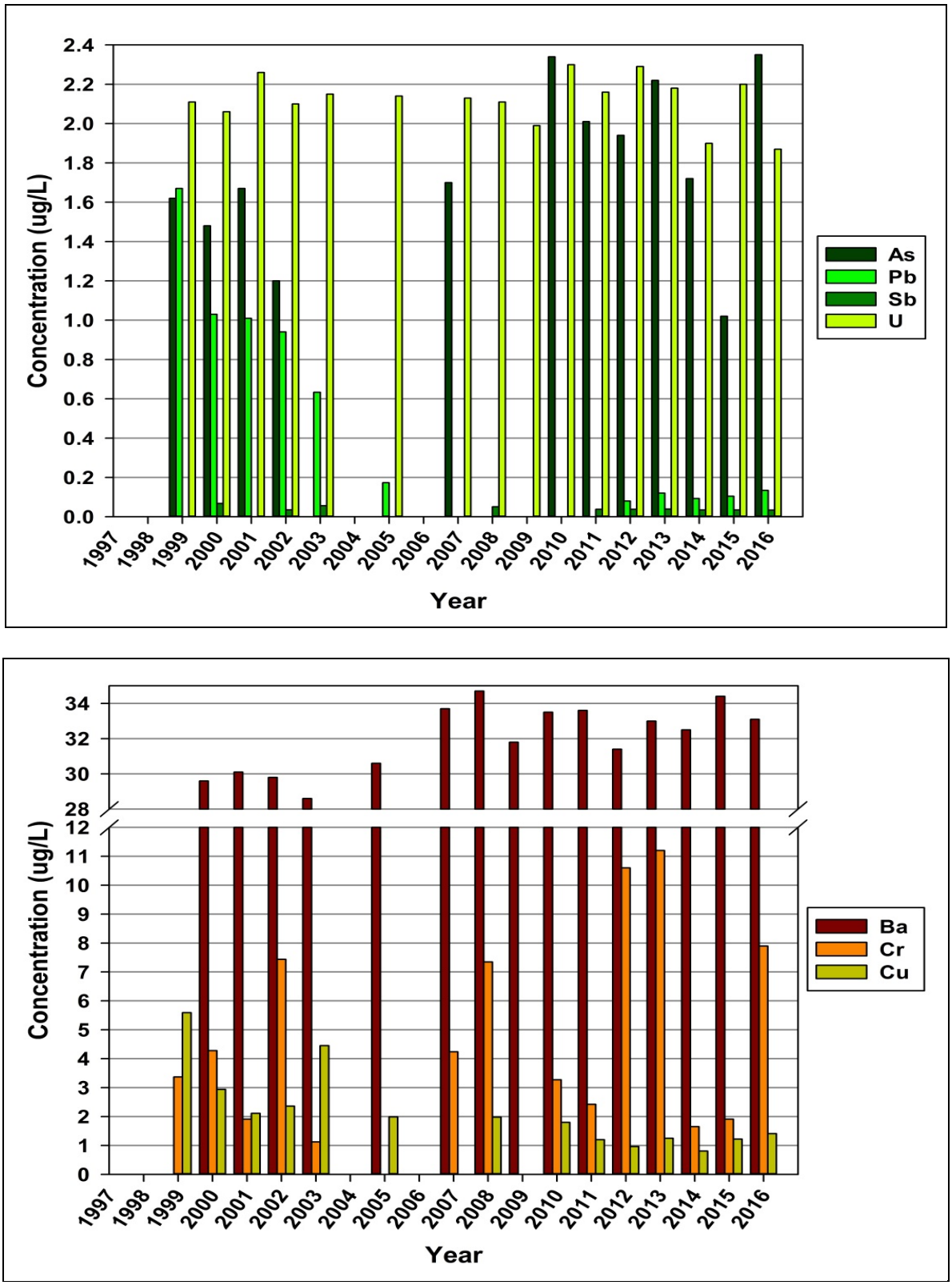
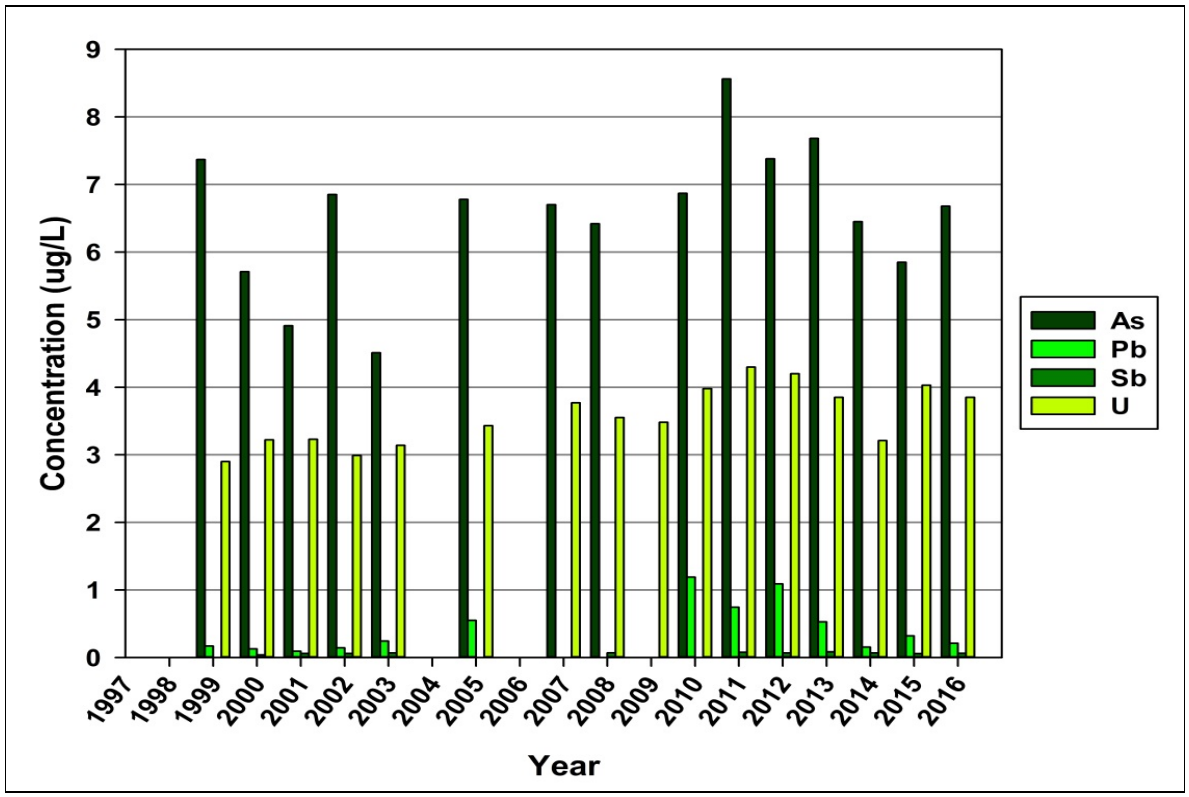


Figure 5-17: Concentrations (µg/L) of Select Inorganic Analytes Measured in Loving Drinking Water (1998 – 2016)



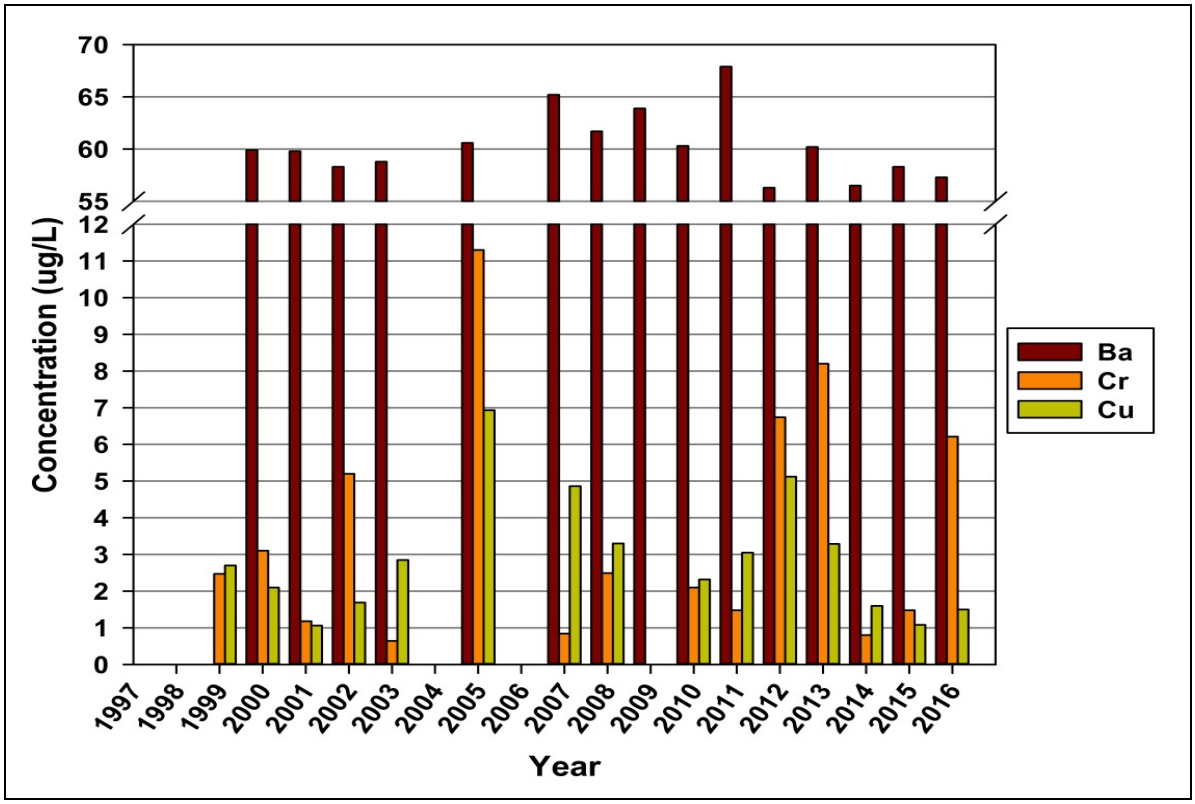
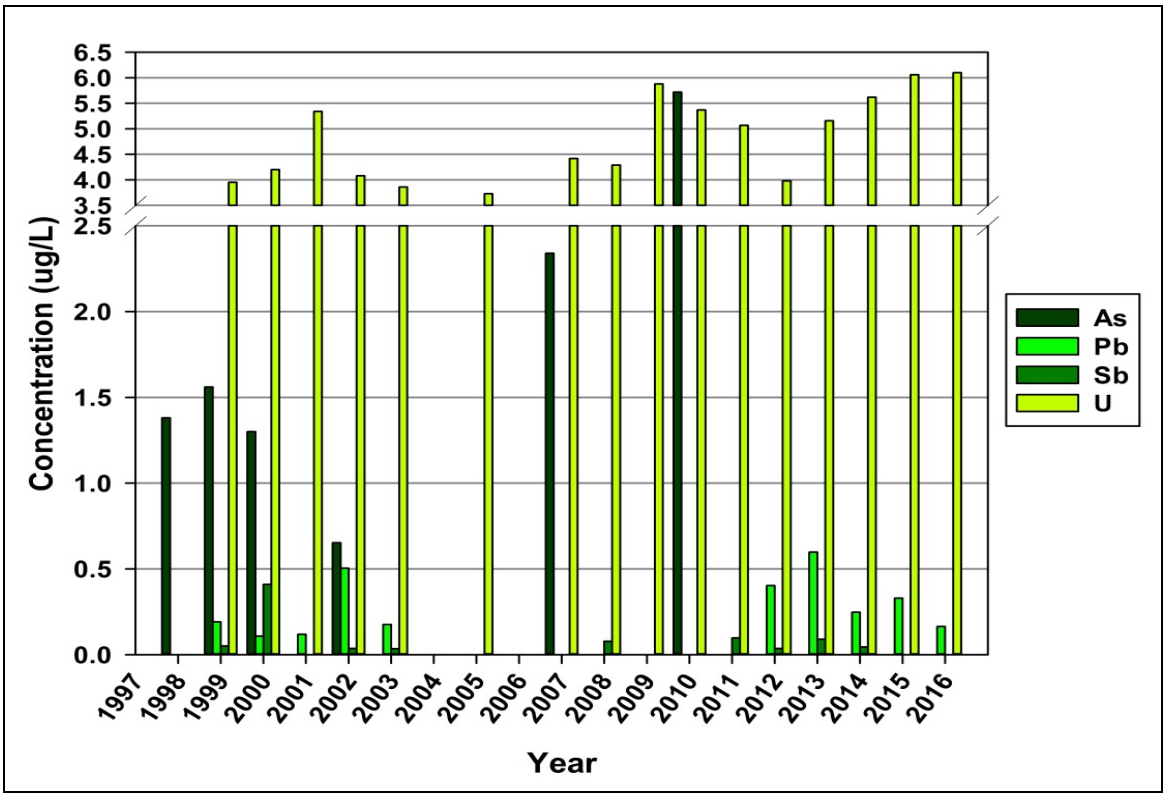


Figure 5-18: Concentrations (µg/L) of Select Inorganic Analytes Measured in Hobbs Drinking Water (1998 – 2016)



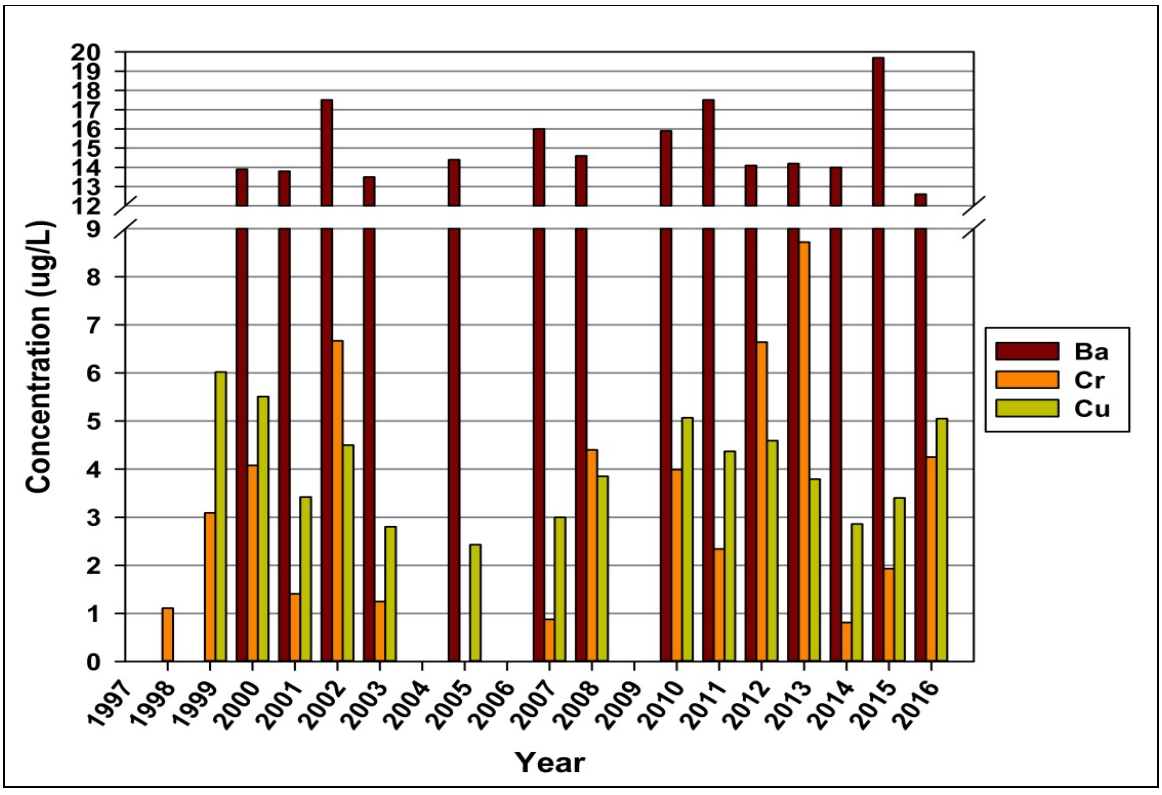
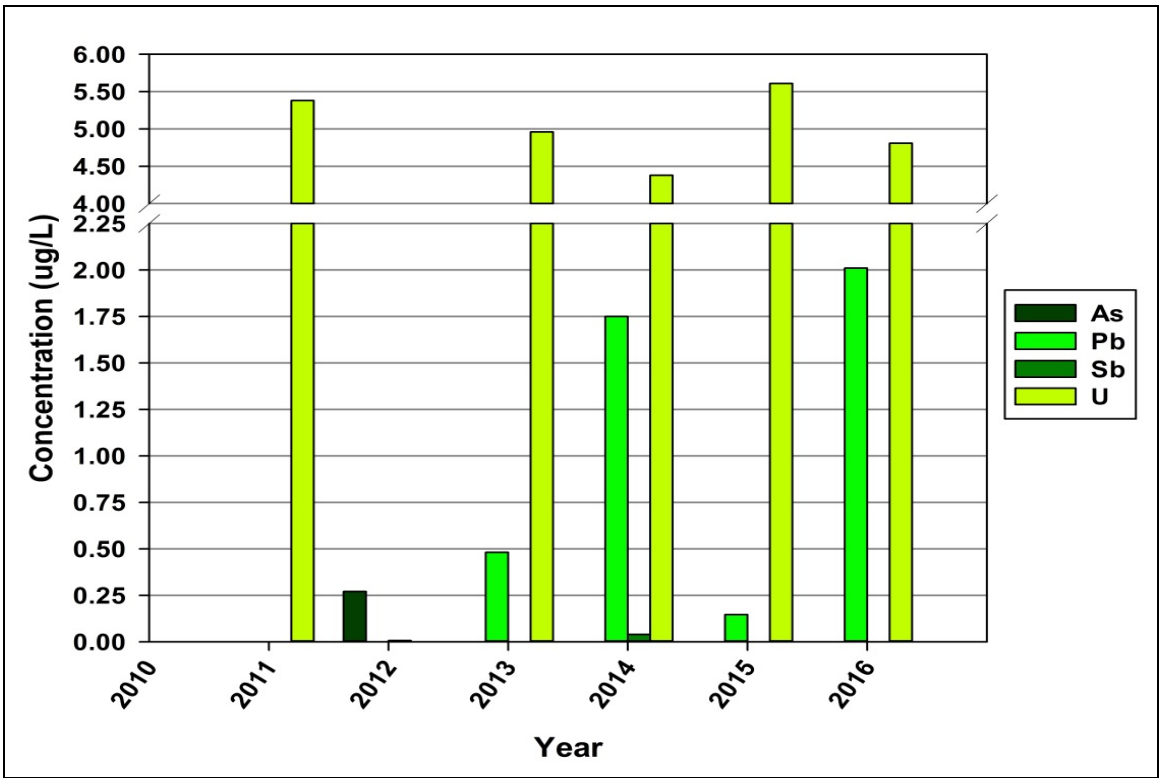


Figure 5-19: Concentrations (µg/L) of Select Inorganic Analytes Measured in Otis Drinking Water (1998 – 2016)



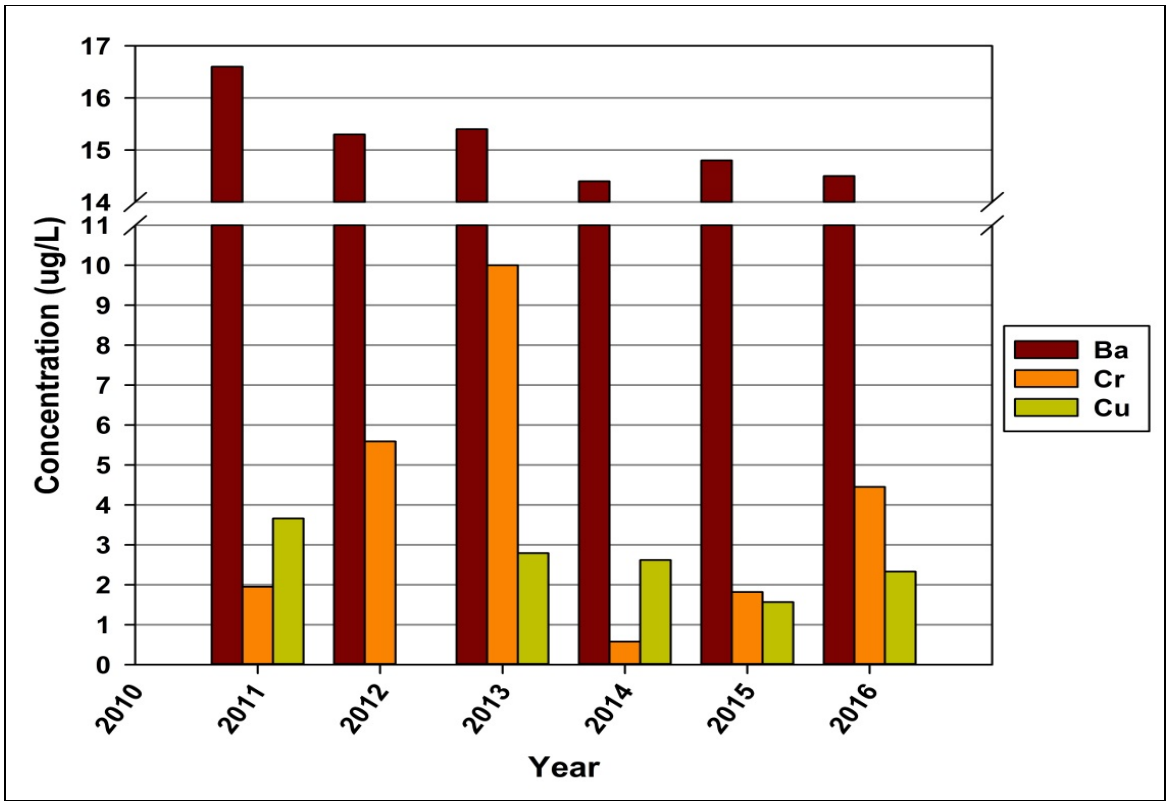


Figure 5-20: Concentrations (µg/L) of Select Inorganic Analytes Measured in Malaga Drinking Water (2011 – 2016)

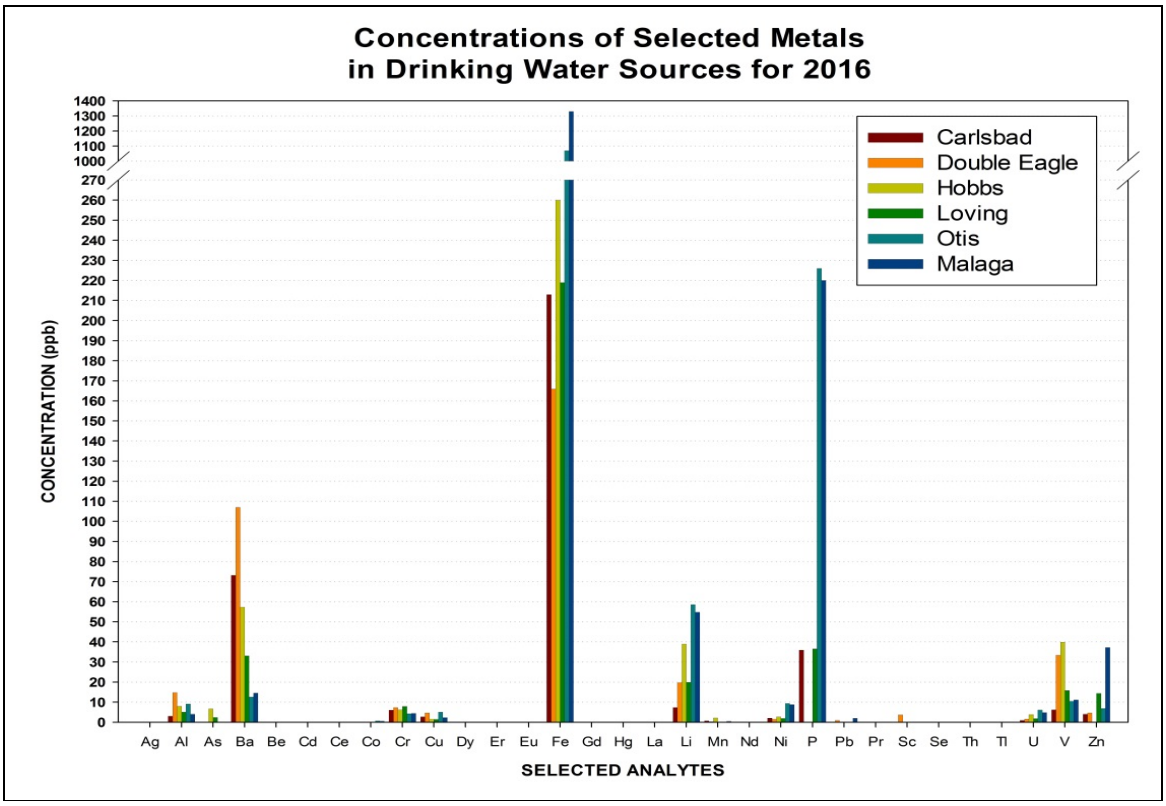


Figure 5-21: Select Metals in 2016 Drinking Water

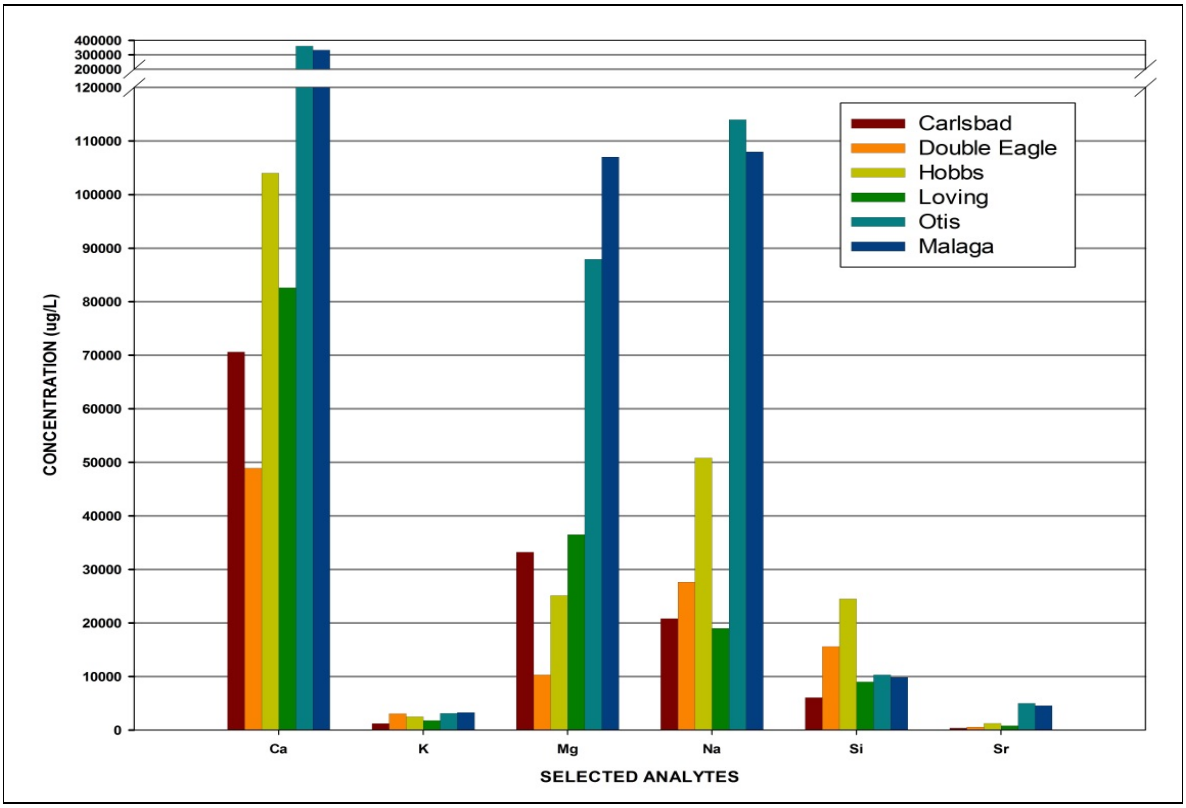


Figure 5-22: Concentrations of Select Metals in Common Salts for 2016 Drinking Water

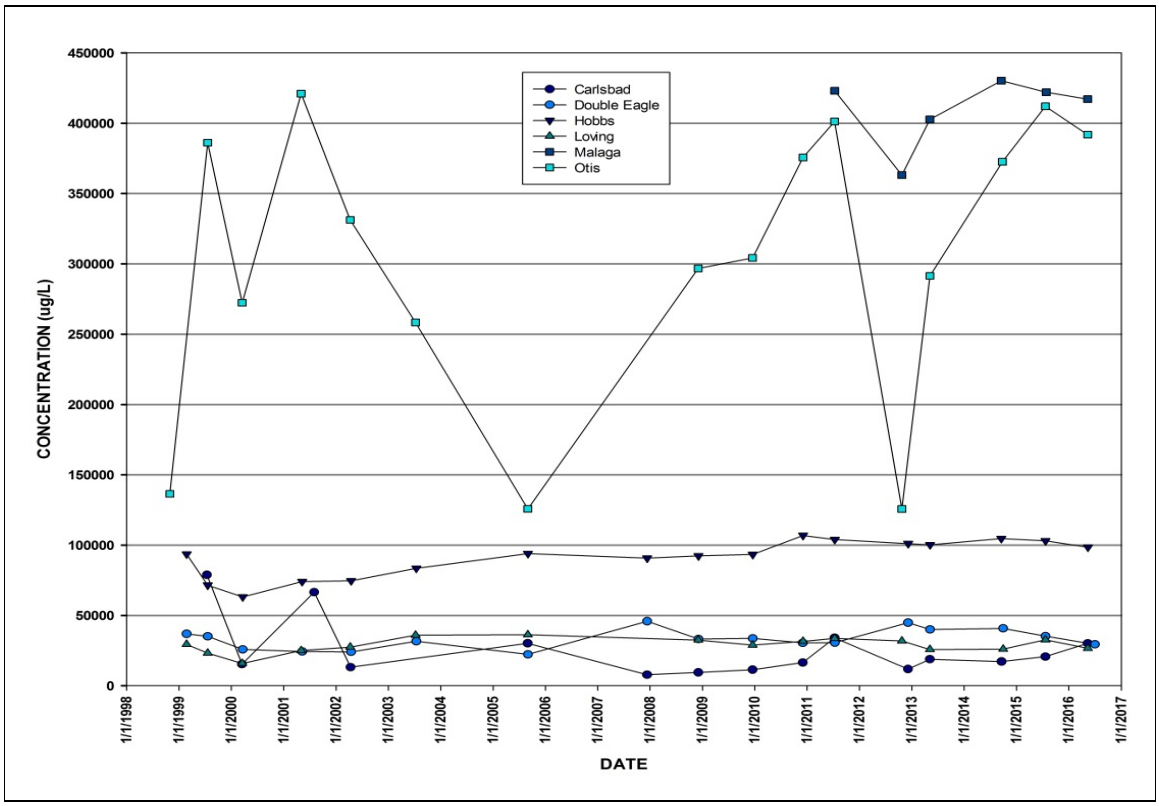


Figure 5-23: Measured Concentrations of Chloride in Drinking Water (1998 – 2016)

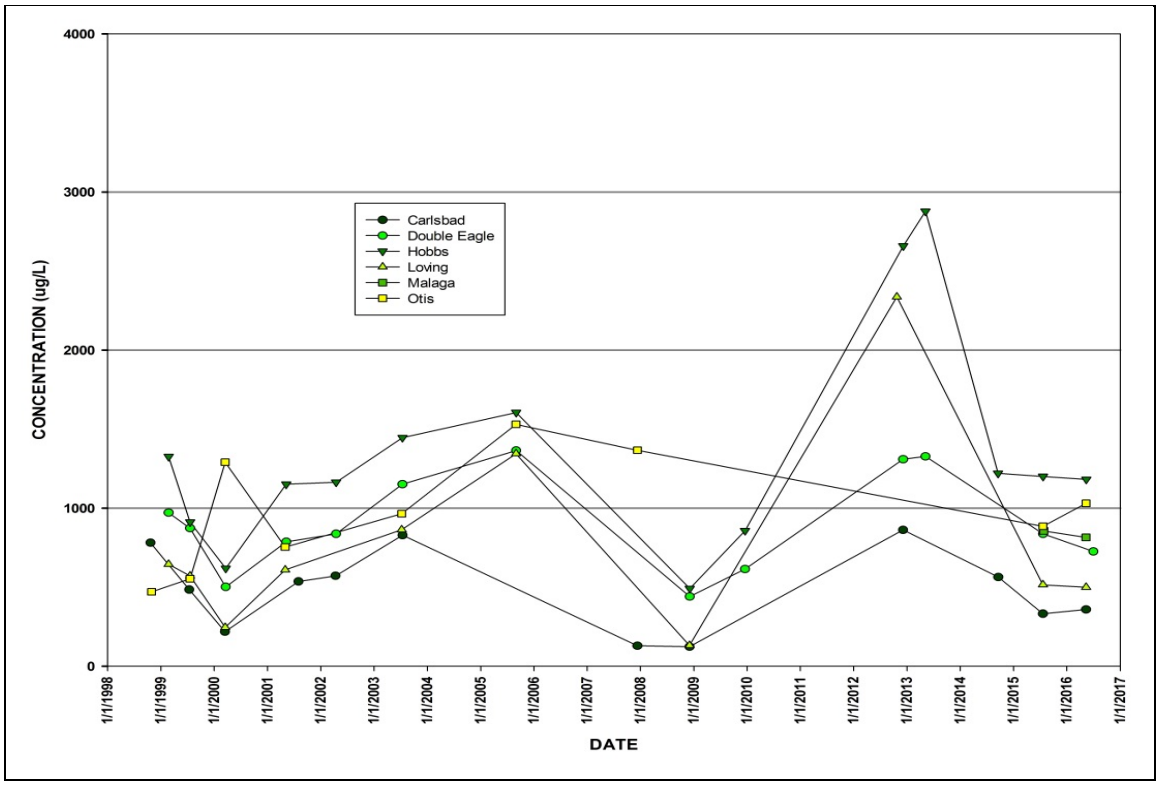


Figure 5-24: Measured Concentrations of Fluoride in Drinking Water (1998 – 2016)

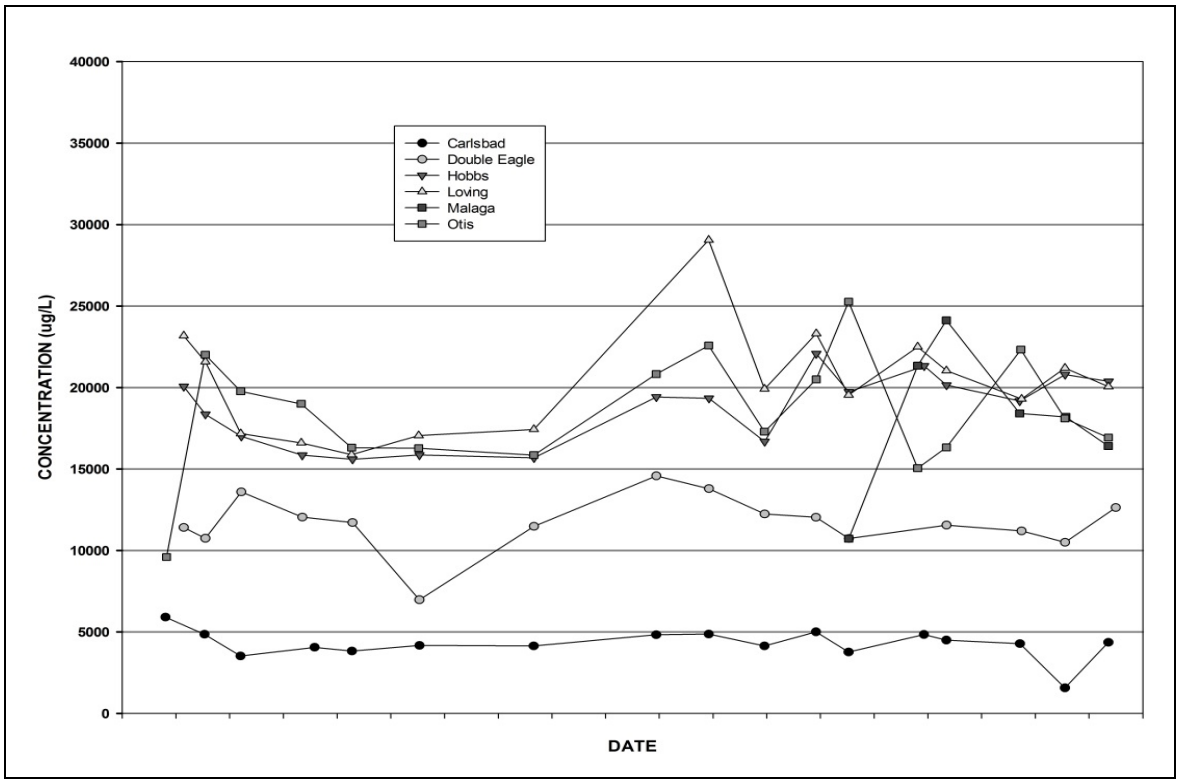


Figure 5-25: Measured Concentrations of Nitrate in Drinking Water (1998 – 2016)

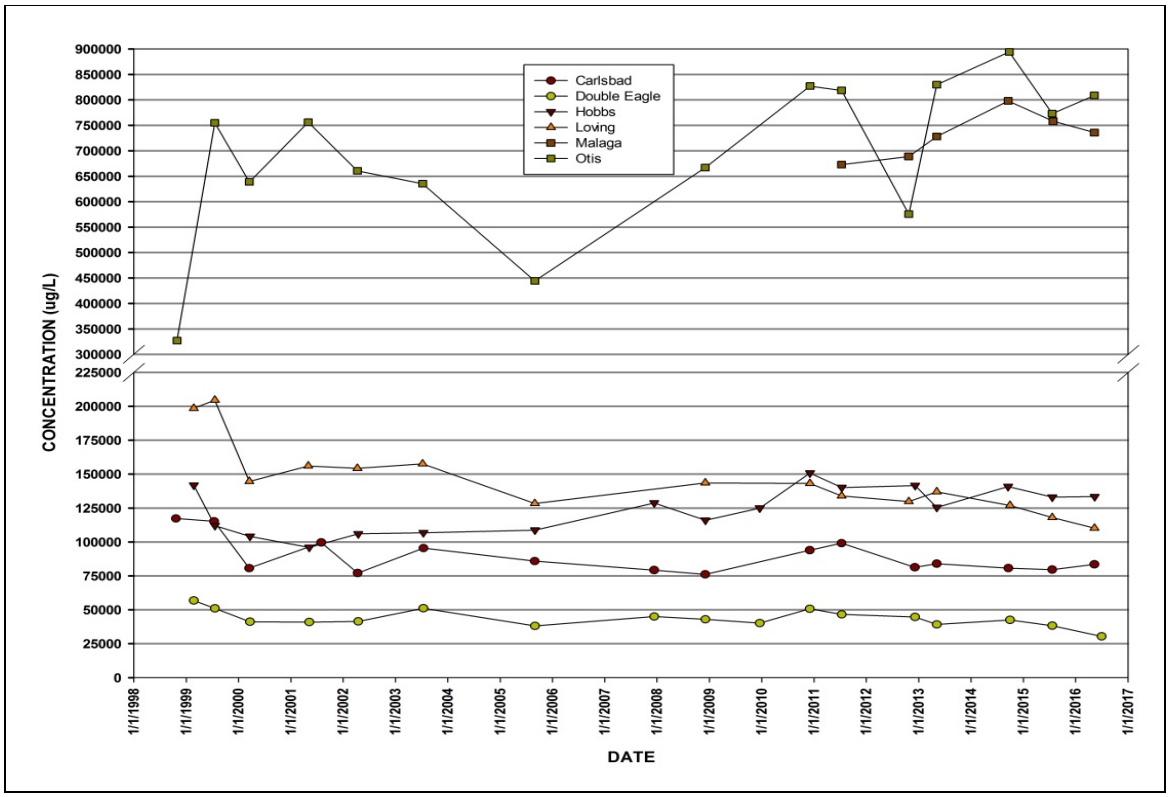


Figure 5-26: Measured Concentrations of Sulfate in Drinking Water (1998 – 2016)

CHAPTER 6

Low Background Radiation Experiments (LBRE)

Scientific Objectives, Biological Models and Experimental Approaches

Objective: To acquire statistically valid Physiological and Molecular data on the Biological response to below-background radiation (at WIPP) and low doses of radiation above-background (at NMSU).

Hypotheses:

1. If the Linear No-Threshold (LNT) model is correct, then radiation significantly below background will benefit organisms using measureable endpoints.
2. If the LNT model is correct, then low levels of radiation above background will inhibit organisms using measureable endpoints.

Biological Models: Organisms spanning prokaryote to eukaryote, from single cell to complex multicellular organisms have been tested underground at WIPP.

1. A radiation-sensitive bacterium (*Shewanella oneidensis*) and a radiation-resistant bacterium (*Deinococcus radiodurans*).
2. Mammalian tissue culture cells, *Cricetulus griseus* V 79 lung fibroblast cells.
3. The nematode, *Caenorhabditis elegans*.

Experimental Approach

At WIPP, the LBRE project has two labs, one aboveground with control incubators where organisms experience normal levels of background radiation (50-100 nGy/hr), and a second below ground in a steel vault where organisms experience a significant reduction of radiation (~0.2 nGy/hr). Additionally, a below-ground control in which a source of radiation (KCl, which naturally has 0.01% ^{40}K) is utilized to mimic normal radiation levels and make the organisms "feel" as if they are aboveground experiencing normal levels of radiation. At NMSU, ^{60}Co coupons that range from 5 µCi to 500 µCi are arrayed in incubators to give varying radiation fields to allow for exposure to above background, yet still low levels of radiation.

Approaches Used:

1. Life cycle incubations.
   i. Growth phase measurements (i.e., cell density, growth rate kinetics, egg-laying rate)
2. Metabolic Measurements.
   i. Stress Indicators (i.e., hydrogen peroxide, catalase and other stress-related proteins)
   ii. Use of inhibitors (i.e., paraquat to study the role of cell-signaling)
   iii. Oxygen and nutrient consumption rates (i.e., use of the redox dye, resazurin)
   iv. Biolog plates – simultaneous measurement of diverse metabolic pathways.
3. Genetic Expression.
   i. Quantitative PCR measures expression of specific genes (i.e., DNA and protein repair)
   ii. Whole genome transcription. Using the RNA *seq* approach, the expression across the organism's genome is sequenced (in collaboration with Santa Fe NM's National Center for Genome Research) and analyzed using a bioinformatics pipeline for genes specifically expressed in the absence of normal levels of radiation.

I. LBRE Accomplishments

Year	Funding	Work Accomplished
2009	$25K	WIPP Aboveground Lab established, Bacterial data acquired
2010	$60K	Initiated WIPP Belowground Lab. Presented paper at Vic Bond Workshop, Richland WA
2011	$60K	Published paper in Health Physics. Gave talk at International LowRad Conference, Barcelona, Spain. At Texas A&M, synthesized ^{60}Co coupons for above background work at NMSU.
2012	$110K	Began collaboration with Italy's Gran Sasso Lab, learned underground tissue culture with V-79 mammalian cells.
2013	$110K	Established mammalian V 79 cell model. Hired Dr. Hugo Castillo as LBRE post-doctoral fellow.
2014	$120K	WIPP work interrupted due to underground radiological release event, established first-of-its-kind experiment underground at Italy's Gran Sasso lab.
2015	$145K	Published paper in International Journal of Radiation Biology. At NMSU, initiated above background radiation experiment. LBRE project post-doc H. Castillo invited to present a paper at the international Dulia-Bio Workshop in Canfranc, Spain, and a presentation to the Carlsbad NM ANS society.
2016	$165K	From WIPP-incubated bacterial cultures, created a 1.8 x 10^9 nucleotide base sequence transcriptome library using RNA *Seq* technology.

II. Personnel (students and postdocs had their salaries funded, some collaborators received travel or small stipend support)

Students: A. Navarrette*, T. Saul, M. Pierce, G. Escobar*, D. Schoederbek*, A. Gonzalez, S. Haake, J. Winder
Post-docs: H. Castillo*, S. Dulal*, X. Li
Collaborators: J. Conca (Forbes Online Magazine), Yair Grof* (NRC-Soreq, Yavna, Israel), R. Guilmette* (Retired from Lovelace Respiratory Research Institute), A. Tabocchini (Italy's Istituto Superiori di Sanita (ISS), G. Cenci (University of Rome), G. Esposito (ISS), W. Van Voorhies (NMSU), M. Tomasi (Univ. Alabama Birmingham, ISS).
*Co-author on published papers

III. Project Introduction

The Low Background Radiation Experiment (LBRE) came from discussions and planning after the 2006 Low-Level Radiation conference in Carlsbad, NM (see following link: Low-Level rad Summit) in which the need for quantitative data on the biological effects of low level, and below-background radiation was emphasized. It was proposed to develop a low-radiation biology lab underground at WIPP. In 2009, Geoffrey Smith (NMSU Professor of Biology) and Adrianne Navarrete (CEMRC radiation technician) initiated the first Biological experiment at WIPP, working out of an aboveground lab locate WIPP. A key component to the LBRE work was the fact that former DOE WIPP Chief Scientist, Mr. Roger Nelson had acquired a 24-ton, 6-inch-thick steel vault that was made from steel manufactured before World War II (from the hull of a Navy destroyer). Nelson had this vault located underground in the N-300 area, just north of the Exo experiment. LBRE scientists installed an incubator in the vault and grew two bacterial species (the radiation-sensitive *Shewanella oneidensis* and the radiation-resistant *Deinococcus radiodurans*) for up to 80 generations. Initial results demonstrated that one of the bacteria (*D. radiodurans*) was inhibited as a result of growing in the reduced-radiation conditions underground at WIPP. Results from this experiment, along with data previously obtained by Ray Guilmette, were published (Smith et al., 2011).

IV. Overview of Results

Below Background Radiation Effects

The biological effects of low levels of ionizing radiation is a challenging and intriguing area of research and meaningful progress will continue in part as the effort becomes more interdisciplinary and innovative. From this initial publication, the LBRE scientists explained their approach "from the other side of background" as Dr Guilmette put it. There continues to be a need for studies documenting the effects of near-background levels of radiation, because without such data, numerous

interpretations can be surmised as to the shape of a dose-response curve at these low levels (Figure 6-1,). The linear no-threshold (LNT) theory states that any level of radiation causes some detrimental effects, but if the line is extrapolated to radiation levels below background, LNT would predict potentially beneficial effects (green line). There is a paucity of data on the biological effects of low-level radiation and without such data, the shape of the dose-response curve is still debated. One of the main goals of the Low Background Radiation Experiment (LBRE) experiment at WIPP is to study the biological effects of radiation "from the other side of background," that is, from below background in the shielded environment that the 2150 ft. of overburden above the WIPP repository provides. Follow-up interest from this publication was generated after an article summarizing the results was written in the on-line *Forbes Magazine* (http://www.forbes.com/sites/jamesconca/2015/09/23/is-radiation-necessary-for-life/#586ceba324ea)

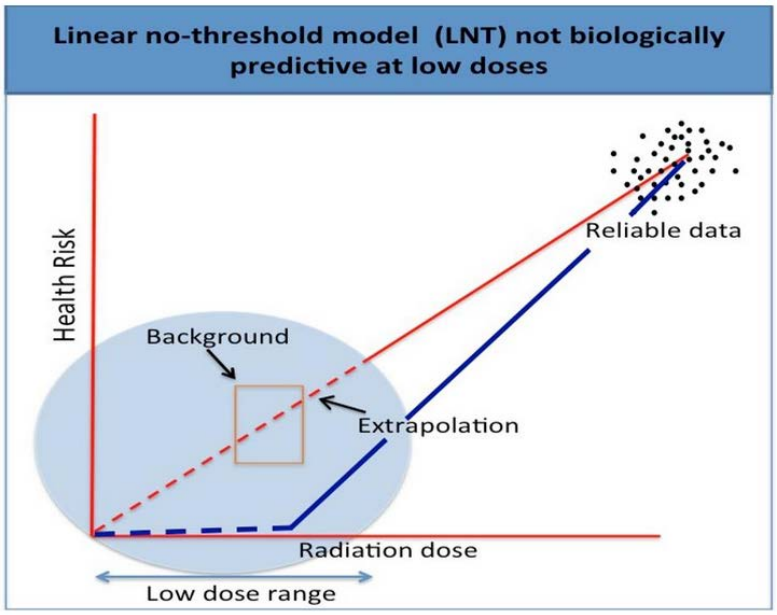


Figure 6-1: There are numerous studies showing detrimental effects of moderate to high levels of radiation, but without enough empirical data on the health effects at near-background levels of radiation, there are more than one possible dose-response curves at and below background (from Smith et al. 2011)

In 2012, Dr. Smith arranged to do a sabbatical at Italy's underground Gran Sasso lab (http://www.nature.com/news/gran-sasso-s-chamber-of-physics-7.4635?article=1.10696) and in particular to learn mammalian tissue culture in context of below-background radiation effects, working with the group led by L. Satta and A. Tabocchinni (http://andeslab.org/workshop5/talks/17_Tabocchini.pdf). When the fire and underground radiation event occurred at WIPP in 2014 the LBRE scientists were not able to work in the underground WIPP laboratory, Smith was invited to work at the Gran Sasso laboratory in Italy in order to continue the collaborative efforts to study the effects of radiation deprivation on

mammalian cells. Using the techniques learned at Gran Sasso, in 2016 LBRE scientists completed two V-79 mammalian cell incubations underground at WIPP and, again in collaboration with Tabocchini's group at Gran Sasso, the team is analyzing the Real-Time PCR genetic responses comparing the reduced radiation environments underground at Gran Sasso and WIPP.
In 2015, LBRE scientists published a paper in the International Journal of Radiation Biology on the results obtained at WIPP (Castillo et al. 2015). In this article, the audience was introduced to the LBRE experimental set-up at WIPP in which they now routinely use an underground control in which a background source of radiation (KCl) is added to give the cells underground a background dose rate of radiation. Figure 6-2 shows the two incubators shielded in the six inch-thick vault made from pre-World War II steel (A), the add-back control having 11.5 kg of KCl lining the incubator (B), the arrangement in the vault of the plus-KCl control incubator which is surrounded by 14 Liters of water shielding the minus-KCl, reduced – radiation incubator (C), and the Monte Carlo N-Particle (MCNP) "heat-map" of the interior of the incubator (D). Without any other sources of radiation in the incubators there was estimated (By MCNP for the minus-KCl incubator and by measurement using a Sodium Iodide detector to measure the plusKCl incubator) to be a radiation dose rate of 0.16 nGy/hr and 71.3 nGy/hr in the minus-rad treatment and the +KCl control, respectively. This 446-fold reduction in radiation underground at WIPP is unprecedented, the closest reduction any other site gets is in the underground "Laboratoire Souterrain" in Modane France which has achieved only a 30-fold reduction in dose rate. (Note that the dose rates reported here do not account for the internal dose rate coming from the K in the growth medium used, which has now been considered in current LBRE publications.)

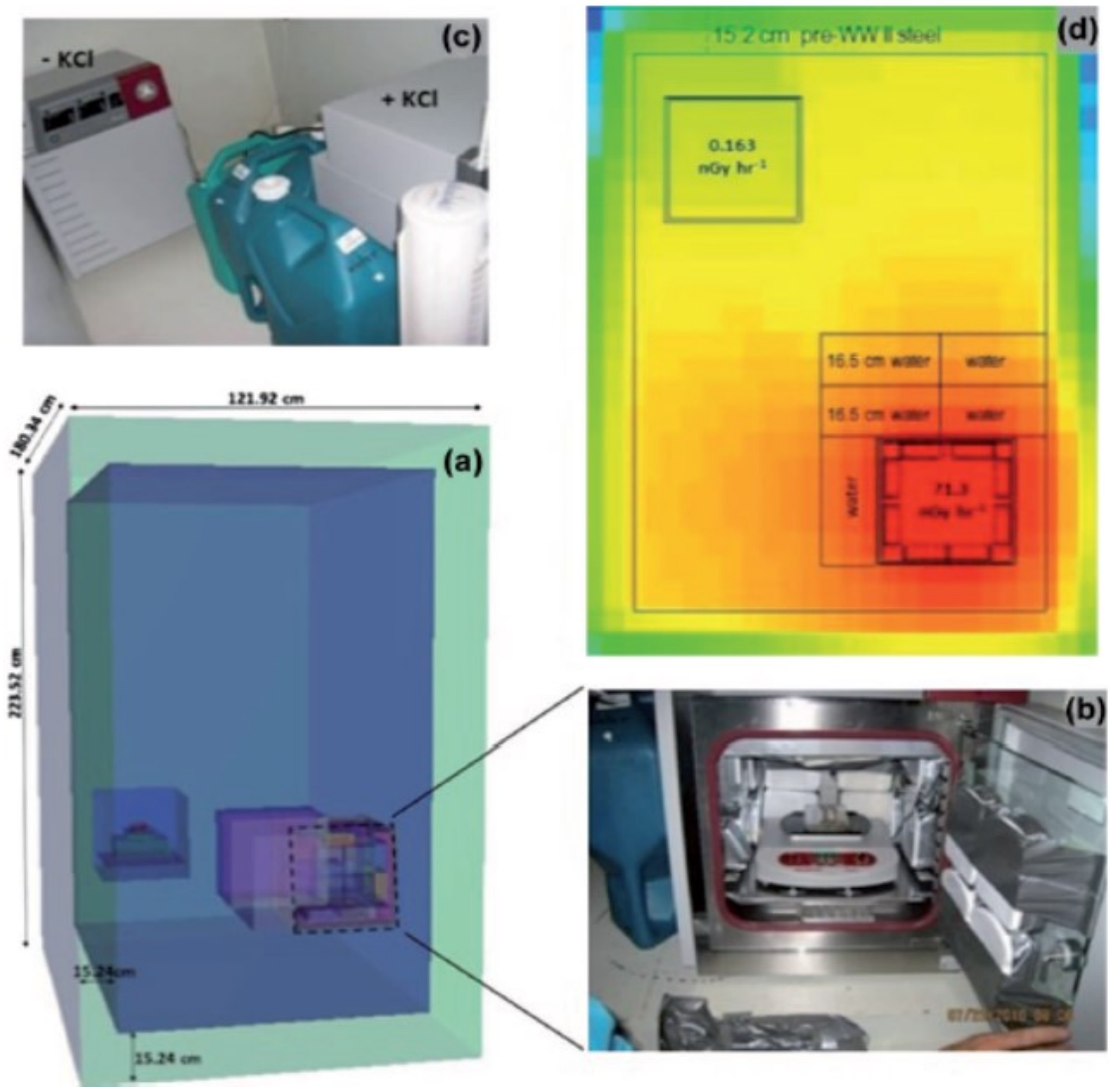


Figure 6-2: Low background radiation experiment (LBRE). (a) Steel vault housing background control (KCl, front) and below-background (minus KCl, back) incubators; (b) Background control incubator showing lining of KCl on internal walls to simulate natural background; (c) Shielding of background control incubator with water-filled carboys to prevent irradiation of the treatment incubator; and (d) Monte Carlo N-Particle (MCNP) modeling of ^{40}K radiation field showing a gradient of a higher (red) to lower (light green) radiation dose and the effectiveness of water shielding (Figure originally published in Castillo et al., Int J Radiat Biol, 2015)

LBRE scientists incubated two species of bacteria, *Shewanella oneidensis* and *Deinococcus radiodurans* underground at WIPP, in the two incubators, the shielded, reduced radiation treatment and the plus-KCl "normal radiation" control. One point to note is that when this experiment was done, the team had limited access to the WIPP underground and were only able to take a limited number of time points during the bacterial growth period. Nevertheless, the growth of both species was inhibited when grown in the reduced radiation treatment compared to the radiation sufficient control (Figures 6a and 6b). To test if this growth inhibition was indeed an effect due to the absence of radiation, the team performed reciprocal controls during

the incubations by removing samples from the rad-reduced treatment and placing them in the rad-sufficient control. As can be seen by the dotted lines in Figure 6-3, growth recovered, returning to control levels corroborating the idea that reduced radiation caused the inhibition.

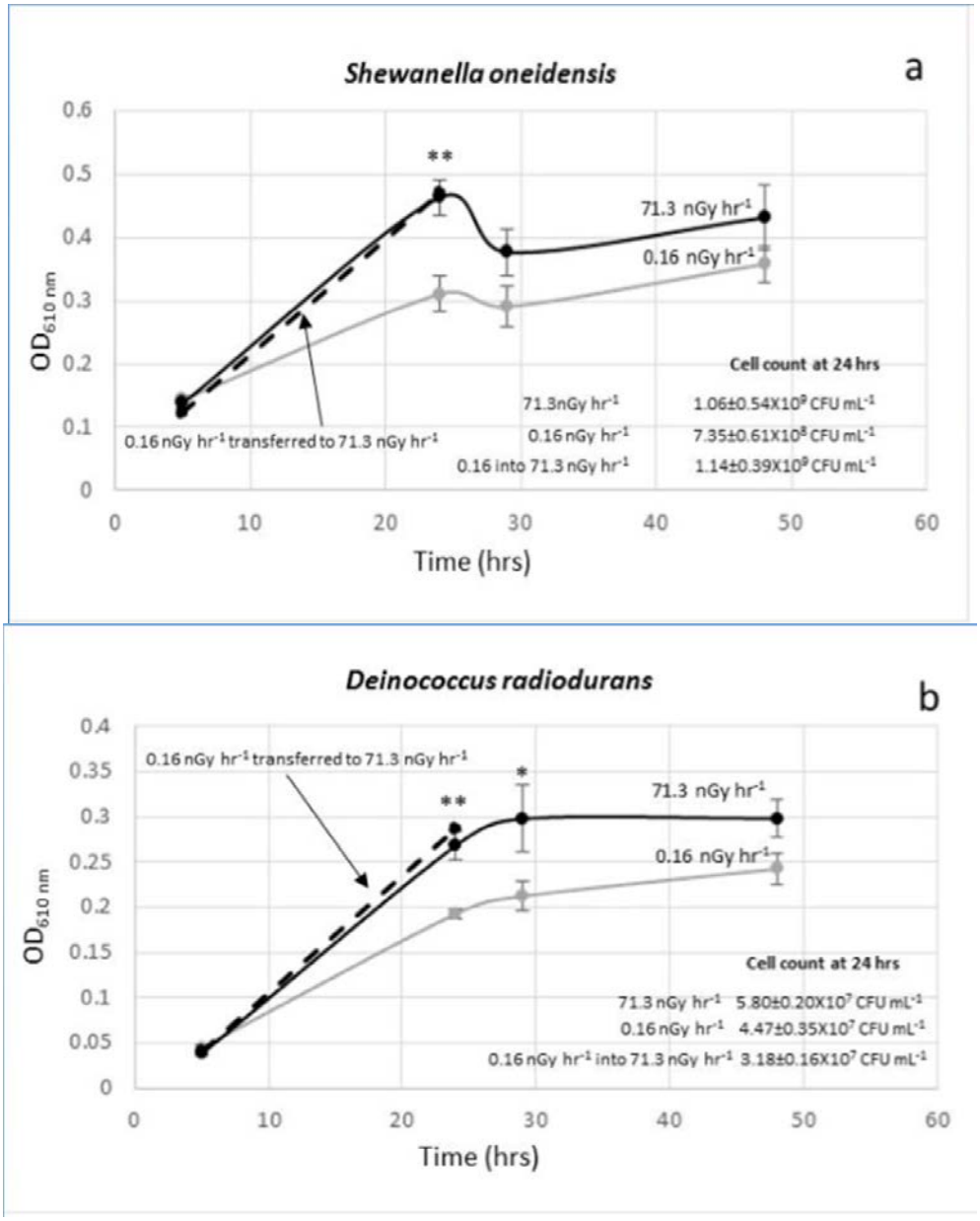


Figure 6-3: Reduction of growth rate of (a) *Shewanella oneidensis* and (b) *Deinococcus radiodurans* at a below-background radiation dose of 0.163 nGy h^{-1}. Error bars indicate the standard error of the mean with n=3 from independent biological replicates. Statistically significant differences are shown as $p \leq 0.05$*, and $p \leq 0.001$**.

LBRE scientists extracted RNA from samples taken at 24 hours from the *Shewanella* cultures and performed Real Time PCR analysis to measure the expression of six different stress genes. At 5 hours, only 1 stress gene was upregulated (the efflux pump, SOA0154), but at 24 hours katB (involved in reactive oxygen species, ROS, response), recA (DNA repair) and again the

SOA0154 gene were all upregulated, indicating a broad-spectrum stress response to the absence of normal levels of radiation (Figure 6-4, blue bars). Interestingly, when RNA was extracted from the reciprocal controls (Figure 6-4, orange bars), all the genes went back to baseline.

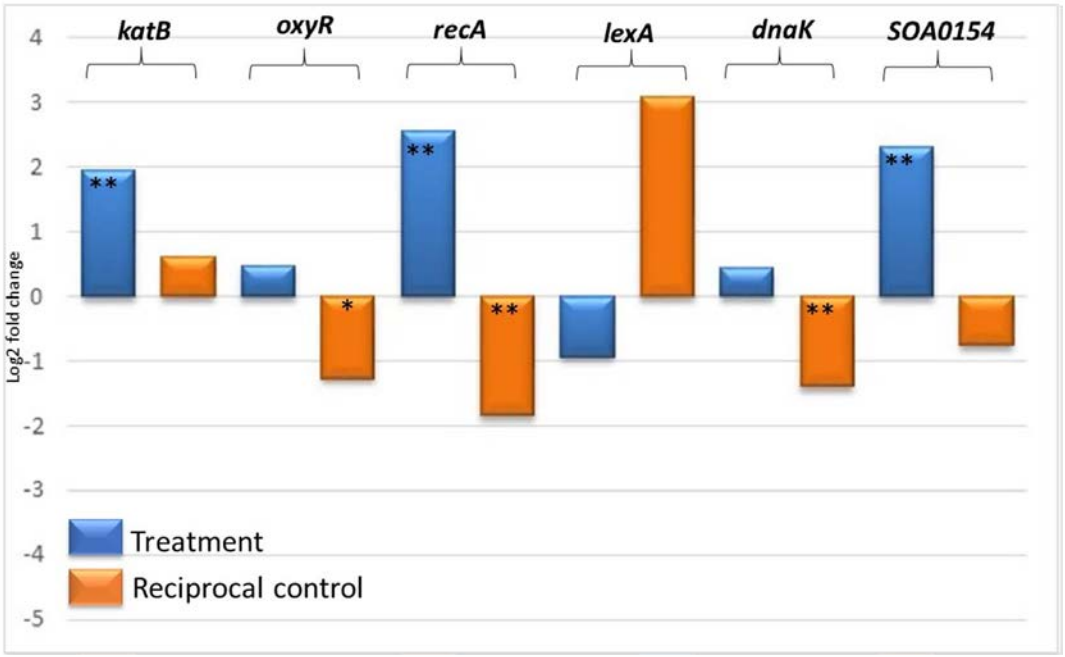


Figure 6-4: Differential gene expression in *Shewanella oneidensis* cultures. Blue bars represent the $\log_2$ fold changes calculated from the gene expression at 0.163 (below-background/treatment) compared to 71.3 nGy h^{-1} (background/control). The orange bars refer to the gene expression in the reciprocal control (cultures grown 24 h in the treatment then transferred to the control). The relative expression and the statistical significance tests were calculated in the gene expression analysis software REST©[20]. Bars represent the mean of 3 independent replicates. Statistically and biologically (≥1/-1 $\log_2$ fold change) significant differences are shown as *($p \leq 0.05$) and **($p \leq 0.001$).

So, the results published by Castillo et al. 2015 confirmed and extended the data reported in our first report (Smith et al. 2011), verifying that in two unrelated bacteria (*Deinococcus* being a Gram-positive, *Shewanella* being a Gram-negative) a significant stress response was documented in response to the absence of normal levels of radiation in shielded growth underground at WIPP.

Low-level, Above Background Radiation Effects

In collaboration with Texas A&M University, LBRE scientists submitted 162, 1 in. x 1 in. cobalt 59 metal coupons to be converted to ^{60}Co by neutron bombardment at the experimental reactor at A&M. Three sets of 54 coupons were generated to give respective sources of 4.9 µCi, 40.2 µCi and 456 µCi. We use 3×3 arrays of these coupons to line an incubator at NMSU to

generate fields of radiation that are considered low-level, but span ranges that include human-relevant levels such as CT scans and nuclear worker exposures. This is part of our effort to span the range referred to in Figure 6-1 that there is a paucity of data.

We have had little opportunity to use these coupons because of a shortage of personnel in the current LBRE grant, but the team has managed to run a series of exposures to one of the bacteria, *Shewanella*. The LBRE team had quantified its response to below-background radiation and now have done the same physiological and genetic assays for the organism while exposed to levels approximately 400 times above background. Interestingly, while the below-background exposure upregulated stress genes involved in ROS response, DNA repair and efflux proteins, the above-background exposure evoked none of these responses (Figure 6-5). This data, intriguing as it is, has not been published yet because the LBRE team has not had the time to do the same experiment with *D. radiodurans*.

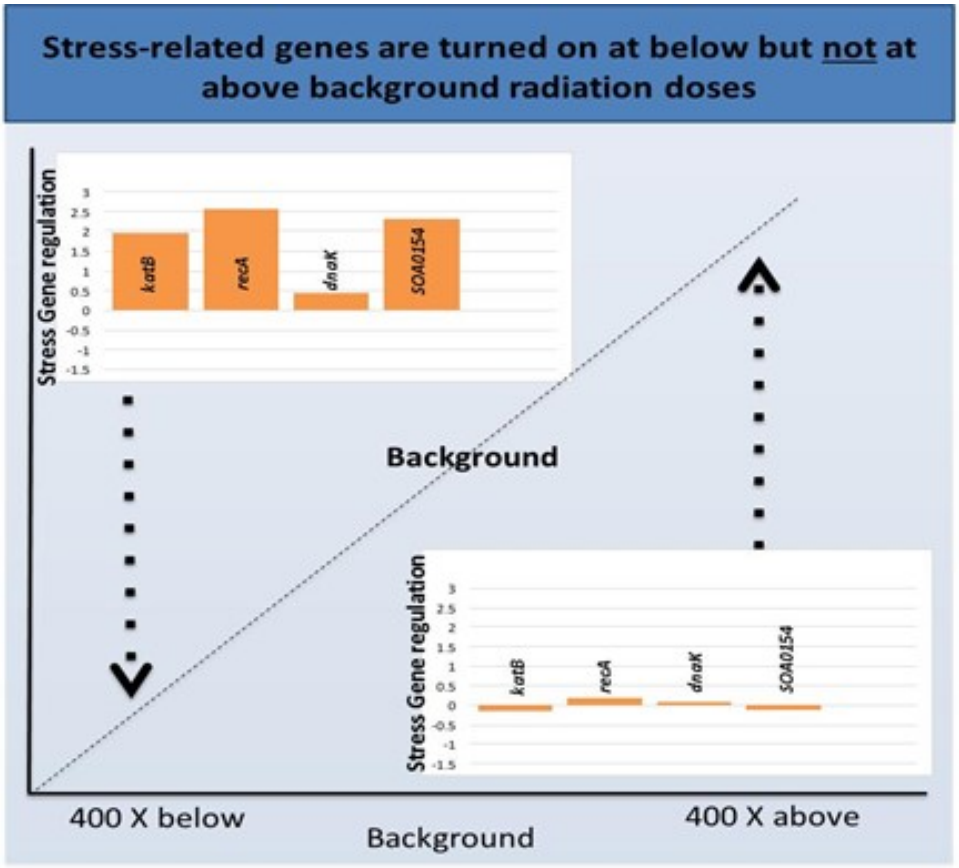


Figure 6-5: *Shewanella oneidensis* was exposed to below background and above background (1.3 uGy/hr) radiation fields and monitored for genetic expression of a set of stress-related genes. Below-background exposure evoked significant up-regulation of the genes (see Castillo et al, 2015 for more details), whereas the same genes were not regulated (up or down) when exposed to above-background exposure. (Winder, Castillo and Smith, unpublished.)

Ancient Life in the WIPP halite?

Vreeland et al. (2000) report that they isolated a 250-million-year-old bacterium from two halite crystals obtained from the WIPP underground. As a scientist who has spent my entire career at the Land Grant University of New Mexico (NMSU), I admittedly have taken some offense to a researcher coming in from West Chester Pennsylvania and making this type of splashy discovery in my own backyard. A "back-burner" project of the LBRE team has been an effort to repeat Vreeland's results. The problem repeatedly encountered is that when using their published halite disinfection method (10 M NaOH followed by 10 M HCl), we have documented the consistent survival of modern bacterial spores, similar to the ones claimed to have been isolated by the Vreeland group (Talamentes, Priebe and Smith, unpublished results). In spite of numerous efforts to find an alternate disinfection technique, the LBRE team has also failed in killing modern spores. LBRE scientists are currently modifying a technique (developed in the 1800's) called Tyndallization in their efforts to develop an effective halite surface disinfection technique. Figure 6-6 shows a few representative efforts along these lines to prove (or disprove) there is Permian Age organisms still alive underground at WIPP today!

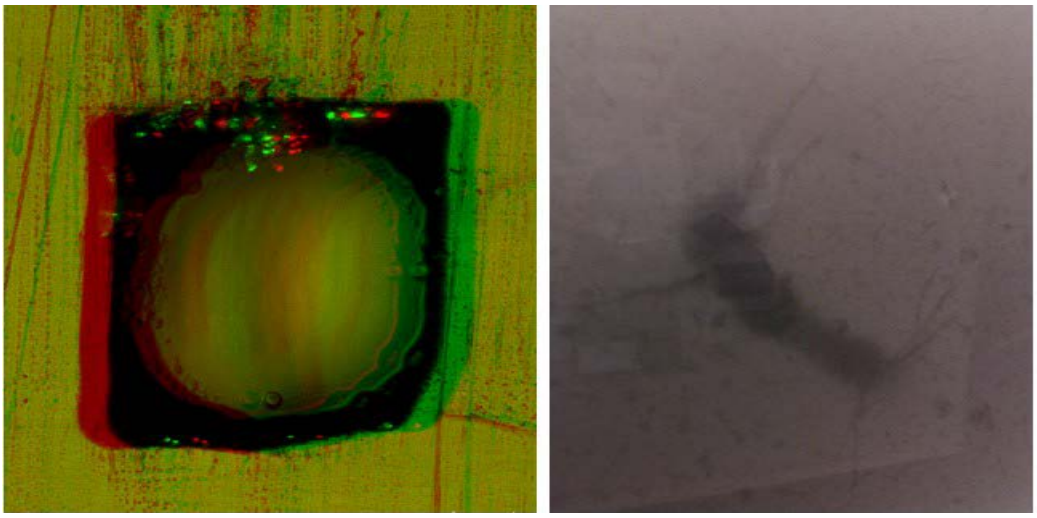


Figure 6-6**:** Left: Stereo-photomicrograph of a water and gas-filled inclusion in a representative WIPP halite crystal and right presence of bacteria-like particles and copious fibers documented by Griffith et al., 2008.

LBRE Result Summary (2016)

- LBRE scientists have documented either growth inhibition or stress gene upregulation in two species of bacteria incubated in the WIPP underground in below-background radiation, in the absence of normal levels of radiation (Smith et al. 2011; Castillo et al., 2015).
- In contrast, when one of these bacteria were exposed to above-background radiation they have not observed any physiological or genetic response.

Together these results do not support the LNT hypothesis that organisms would be stimulated in reduced-radiation conditions and inhibited in the presence of above-background radiation levels. This work adds to the growing body of evidence that the biological response to radiation levels is non-linear.

- Work is underway to test for the biological responses to below background and low-level radiation in other model organisms, including V-79 mammalian tissue cells (*C. griseus*) and the nematode (*C. elegans*). Whole-genome expression analysis (*RNA seq*) is also in progress.
- The effort to verify the Vreeland et al. proposal that there are microbes still living in Permian Age WIPP salt continues (with the application of Tyndall's work from 1877).

CHAPTER 7

Whole Body and Lung *In Vivo* Measurement

The Lie Down and be Counted (LDBC) program, a component of the Carlsbad Environmental Monitoring and Research Center (CEMRC) WIPP-EM environmental monitoring program, began in 1997 as an outreach service to the public: (1) to support education about naturally occurring and manmade radioactivity present in the environment, (2) to monitor the radionuclides present internally in the bodies of persons residing within 100 mile radius of the WIPP location, and (3) to evaluate and improve upon the uncertainties associated with bioassay methodologies using the information obtained from these measurements.

The LDBC program monitors internally deposited radionuclides by non-invasive in-vivo radiobioassay of lungs and whole body. The program provides a scientific understanding of how transuranic (TRU) nuclear waste disposed at the WIPP may impact the residents living within a 100-mile radius of the WIPP repository. This program is provided free of charge to residents living within a 100-mile radius (Figure 1) of the WIPP site as an outreach service to the public and to support education about naturally occurring and man-made radioactivity present in people in the local area around the WIPP. The data collected prior to the opening of the WIPP facility (March 26, 1999) serve as a baseline for comparisons with periodic follow-up measurements that are slated to continue throughout the approximate 35-year operational phase of the WIPP project.

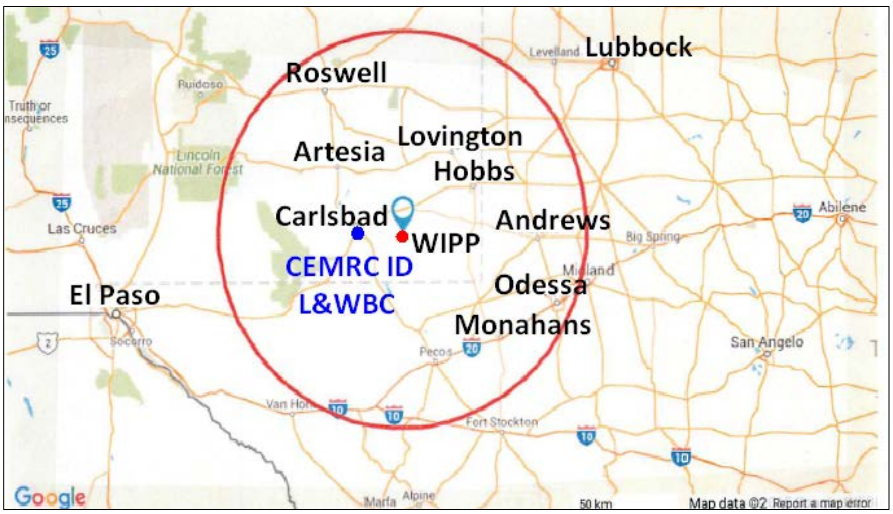


Figure 7-1: Map showing the area within 100 mile radius of the WIPP site.

The Carlsbad Environmental Monitoring & Research Center (CEMRC), facility shown in Figure 7-2, was created in 1991, as a division of the Waste management Education and Research Consortium (WERC), in the College of Engineering at New Mexico State University (NMSU), Las Cruces, NM. CEMRC is funded through a financial assistance grant from the U.S. Department of Energy (DOE).

In-vivo Radiobioassay Lung and Whole body Counting Facility

The Internal Dosimetry department of CEMRC manages the lung and whole body in-vivo radiobioassay counting facility which consists of a large shielded counting chamber (Figure 7-2), instrument control workstation, two change rooms with showers and toilets, and a reception area.

Figure 7-2: Shielded chamber for lung and whole body counting

Routine examinations are generally performed from the instrument control workstation, although the configuration of the software and hardware allows counting and review of spectra from any of two remote X-Terminals. The instrument control workstation includes a video display terminal (VDT) and intercom (Figure 7-3) that are used to monitor subjects during the counting. An additional VDT and intercom are located in the office of the primary instrument operator. A compact stereo has been installed so that counting subjects may listen to music or the radio during the counting. (Figure 7-3). The facility was completed in the summer of 1997. Construction materials were selected for low naturally occurring and anthropogenic radioactive contamination.

Figure 7-3: Instrument control workstation, video display terminal (VDT) and Intercom

Figure 7-4: Oxygen monitor, speakers, video camera and intercom in the chamber, an operator fitting the lung detectors on a volunteer

Figure 7-5: Inside the LDBC Shielded Chamber

The i*n vivo* bioassay facility occupies approximately 90 m^2 (966 ft^2) and provides the primary analytical infrastructure for the internal dosimetry program. The facility includes a large shielded counting chamber (Figure 7-2), dedicated instrument control workstation, two change rooms with showers and toilets, and a reception area. The counting chamber measuring 2.4 m ×2.4 m × 2.4 m is constructed of 25.40 cm thick cast iron, with a full graded-Z liner consisting of lead, tin and stainless steel. The cast iron composing the chamber was produced for industrial use prior to 1945, and re-cast for the chamber using a specially selected foundry, resulting in very low background radiation from anthropogenic and naturally occurring constituents. Signal processing electronics are located outside the counting shield next to the instrument control workstation. Inside the shielded chamber, there is an oxygen monitor, speakers to listen to music during the counting of the subjects, backup lights, voice activated intercom for the subjects to communicate with the operator at any time during the counting, and an activation switch to open the chamber from inside (Figure 7-4). Lung detectors are on top of the bed, the whole body detectors are positioned under the bed (Figure 7-5). The whole body detectors face the torso and upper leg parts of the body.

Conditioned air is provided to the shield from the Center's centralized heating and cooling units. The air is high efficiency particulate air (HEPA) filtered just prior to entering the room to remove any particulate that may contain radioactive contamination. In addition, an oxygen monitor is installed inside the shield to monitor oxygen levels in the room.

Inside the shield, a specially designed counting bed and positioning mechanism is secured to the floor of the chamber (Figure 7-4). The bed was designed to allow for simultaneous lung and whole body counts and is constructed from low background steel that provides minimal attenuation of photons between the counting subject and the whole body counting detectors (8% attenuation at 662 keV gamma energy). The positioning mechanism for the lung counting detectors was designed to support four, 3800 mm^2 detectors mounted in two cryostats. The mechanism provides for longitudinal and vertical positioning as well as independent lateral angle and longitudinal tilt adjustment between the two cryostats (Figure 7-5). Sufficient positioning flexibility is provided in the positioning mechanism such that other body loci, such as skull, liver, wounds, and thyroid, can be examined.

The *in vivo* radiobioassay facility was commissioned in July 1997 and is completely ANSI compliant (ANSI N13.30-1996 and 2011)

DOELAP ACCREDITATIONS

The Department of Energy Laboratory Accreditation Program (DOELAP) grants *in vivo* radiobioassay accreditation by assessing direct (*in vivo*) radiobioassay categories including ^{238}Pu, ^{241}Am, ^{238}U, ^{235}U, fission or activation products (^{57}CO, ^{60}CO, ^{134}Cs, ^{137}Cs and ^{54}Mn) in the lung counting system, and fission or activation products (^{57}CO, ^{60}CO, ^{134}Cs, ^{137}Cs and ^{54}Mn in the whole body counting system, through participation in performance testing by the Department of Energy Laboratory Accreditation Program (DOELAP) for radiobioassay and on site assessment. DOELAP accreditation dates starting from 1999 to the present for CEMRC ID lung and whole body counting facility as the service laboratory for the WIPP are listed in Table 7-1.

Table 7-1: DOELAP accreditation dates for the CEMRC ID Lung and Whole Body counting facility

	DOELAP accreditation effective date	DOELAP accreditation
1	1/9/1999	11/19/2003
2	8/19/2003	8/1/2006
3	8/1/2006	8/1/2009
4	9/30/2009	November, 2013 (actual date currently not available)
5	1/6/2014	8/1/2016
6	12/12/2016	8/1/2019

DOELAP accreditation continues to remain valid even after the effective date as long as the laboratory is in the process of renewal and is participating in the current performance testing program.

Summaries of baseline scientific studies conducted prior to the opening of the WIPP facility – CEMRC, 1996 Report:

For the interpretation of internal dosimetry measurements, comprehensive baseline studies in different disciplines are essential. On-site baseline studies are valuable because, values need not be prorated or postulated from some other off-site cohort studies which would not be representative of the WIPP conditions.

Eight major studies were conducted- prior to the installation of the WIPP facility, and are listed below:

Survey of factors related to contaminant exposure and perceptions of environmental risks in Carlsbad, Loving, Malaga, and Hobbs, New Mexico

In addition to people working at the WIPP, people who live and work close to the facility in Eddy and Lea counties are at risk of potential exposure from any releases of contaminants that could occur at the WIPP. There are two population centers in Eddy County within a 30-mile radius of the WIPP. Carlsbad, 26 miles west of the facility is more like an urban community. Loving-Malaga, 18 miles southwest of the facility, is more like a rural community. The city of Hobbs is located 40 miles northeast of the WIPP site in Lea County. Both Carlsbad and Hobbs are similar in size and many characteristics. Based on the distance from the WIPP and the direction of prevailing winds, Hobbs is less likely to be affected by any release of contaminants at the WIPP and, therefore, represents a possible reference population for purposes of future comparisons with populations nearer to the WIPP. This study provided data on population characteristics and lifestyles that will be useful for estimating the health risks associated with potential releases of wastes from the WIPP. In general, response patterns for Carlsbad and Hobbs were similar for the parameters surveyed, indicating that using future data from Hobbs as a reference population is feasible.

Cancer Incidence rates in Eddy and Lea Counties, New Mexico, 1970-1994

This report presented by Gilliland and Lambert, Epidemiology & Cancer Control Program, University of New Mexico Health Sciences Center described a summary of cancer incidence rates for the populations of Eddy and Lea counties during the last twenty years. The results include several instances of large variations and clustering of cancer incidence rates that are likely sampling artifacts associated with small population sizes and relatively rare cancer types. Temporal changes in incidence of some cancer types (such as prostate cancer and female breast cancer) are thought to be strongly influenced by changes in detection methods. This history of past variability is important in assessing and interpreting future cancer incidence data, relative to potential effects of exposure to materials to be disposed of at the WIPP. Given the relatively small population sizes in the immediate region of the WIPP (30 residents in a 10 mile radius, and 2,000 within 20 miles), the historical variability in cancer incidence rates (as revealed in this study), and the potential of confounding effects from

changes in medical technology, health habits and other population attributes, it would be very difficult to demonstrate that an increase in cancer incidence is the result of exposure to contaminants at the WIPP.

Statistical Issues in the Design of a Bioassay Surveillance System for Populations near the Waste Isolation Pilot Plant

A report by Gilliland, Lambert, Stidley, and Trinkaus, Epidemiology & Cancer Control Program, University of New Mexico Health Sciences Center evaluated alternative strategies for surveillance of the population body burdens of radionuclides in persons living near the WIPP. Although specific analytical methods for bioassay surveillance currently are under development, a variety of *in vitro* and *in vivo* methods may be used. In *in vitro* bioassay methods, radioactivity is measured in samples of urine, feces, blood, or other tissues. In vivo methods employ external detectors to make measurements of radiation emanating from within the body. The ability of these methods to detect increases in radioactivity in potentially exposed groups is dependent both on selecting accurate scientific measurement methods and on obtaining measurements from adequate numbers of persons. This study identifies epidemiological and statistical issues relevant to design of a surveillance program to establish baseline levels of radioactivity in the population before the WIPP begins to receive waste and to detect increases in population mean body burdens of radionuclides after the facility begins operations.

The minimum detectable amount (MDA) is the amount of radioactivity that can be detected with a false negative (Type II) rate of < 5% from samples of body fluid or from external measurement of body burden. If the proportion of measurements below the MDA from a population sample does not exceed 30%, conventional statistical methods (e.g., t-test) can be used to estimate the sample sizes required to detect significant differences between groups. Some of the more recently developed bioassay methods may be sensitive enough to meet this performance criterion and thus would support the use of conventional methods to estimate sample sizes. Published literature and consultation with bioassay experts suggest that, using standard detection technologies, the detection of background radioactivity from Pu above MDAs will be extremely rare in the general population without occupational exposure. The detection of radiation from other radionuclides, such as ^{137}Cs is expected to be much higher. Depending on the technology used, the observation of an MDA for some radionuclides in the general population living in the vicinity of the WIPP may be less than 1 in 10,000 persons. One statistical approach applicable to this type of data is the use of a binary outcome variable, such that an individual's measurement is considered to be negative" if below the MDA or "positive" if above the MDA.

This study identifies several constraints posing substantial difficulties in the use of conventional statistics to accurately estimate population mean body burden of radioactivity. The area where the WIPP is sited is sparsely populated, and the numbers of potentially exposed persons available for bioassay are smaller than the sample sizes needed to detect small increases

in the population mean, under some detection scenarios. For example, the analyses indicate that the number of people living closest to the WIPP facility (30 residents in a 10-mile radius, and 2,000 within 20 miles) is too small to use an independent sampling design for surveillance, even if very low detection limits are possible. The use of cohort designs in sampling may be more effective, although this would still require a detection level low enough to produce continuous data. In addition, small decrements in the specificity of the analytic methods will introduce large amounts of error into the surveillance system, greatly increasing minimum sample size requirements.

The effects of graded-Z lining on low-energy background in shielded Room used for lung examination

An investigation by Webb, Fingleton, Lee and Spitz, 1996, indicates that a cast iron (Fe) enclosure (shield) is commonly used in whole-body counting to reduce cosmic and terrestrial background radiation so that small amounts of internally deposited photon, X-ray, or bremsstrahlung emitting radionuclides can be detected. As cosmic radiation, mainly muons, interact with the thick Fe walls of the shield, a distribution of low-energy secondary and tertiary photons are produced. These photons can then interact with the whole-body detectors resulting in an increase in the Compton continuum (background) thus reducing the sensitivity of a whole-body measurement. To address this problem, health physicists historically have added a graded-Z liner (Z represents the charge of an element) to the inside of the counting shields.

For both the Bottle Manikin Absorption (BOMAB) and the human subject, there was little or no reduction in background radiation achieved by the application of any shield/liner-layer combination for the Pu region of interest. For the BOMAB and human subject, literature comparable reductions in background radiation were observed for the full graded-Z liner and the Fe/Pb+Cd shield/liner-layer combination for the Am region of interest.

Atmospheric monitoring network design for detecting acute radiation release

A pilot study conducted by Macintosh, Ozkaynak, and Spengler, 1993, Harvard School of Public Health Pilot using high-volume atmospheric aerosol sampling have been conducted near the WIPP since 1993. The purpose of the studies has been to characterize, by size, the temporal variability in aerosol mass and actinide composition. The methods described provide a tool to generate numerical data that can be used for comparative purposes during the network design process. An important aspect of the model is its ability to optimize network design to provide the most cost-effective monitoring strategy. This method provides qualitative estimates of the expected performance of alternative monitoring strategies. Although some meteorological uncertainty is accounted for in the model, the methods described here provide point estimates of expected activity concentrations and monitor needs. As with any deterministic model, these point estimates are subject to uncertainty regarding the true value or distribution of certain input

parameters (e.g., wind direction at time of release) and stochastic variability inherent in other parameters (e.g., variation in wind direction during transport). In addition, the physical characteristics of the plume, effective release height, particle size distribution, and the state of the atmosphere also contribute to the model prediction uncertainty. For example, the model does not include parameters to account for the atypical "plume" that would result from chronic low-level releases.

Biomarkers for public health surveillance of genotoxic damage

Investigation by Gilliland, and Lambert, Epidemiology & Cancer Control Program, University of New Mexico Health Sciences Center evaluated the utility of the currently available biomarkers for somatic mutations and chromosomal aberrations related to ionizing radiation. Specifically, the review evaluated the potential applicability of various methods for monitoring for the occurrence of genetic damage in the human population living near the WIPP. At the present time, assays are not sufficiently developed to justify their use to monitor populations living close to the WIPP. Variability needs to be reduced by improving blood sample collection, handling, and analytic methods, and better characterization of the host factors influencing intra- and inter-individual variability. Both chromosomal aberrations and mutations in erythrocytes (GPA variants) and T cells (TcR mutants) hold promise for future use in population monitoring.

Determination of atmospheric $^{239+240}$Pu in the vicinity of the Waste Isolation Pilot Plant

The source of atmospheric Pu and other actinides within and adjacent to the WIPP site prior to receipt of wastes can be considered to be the result of global fallout from nuclear weapons testing, destruction of satellites carrying nuclear power sources, and accidental releases from nuclear industry installations (Lee, Webb, and Fingleton, 1996).

For purposes of environmental regulatory compliance, the Argonne National Laboratory, near Chicago, Illinois, has been monitoring $^{239+240}$Pu concentrations in air since 1973. During the period of 1973 to 1982, the $^{239+240}$Pu aerosol concentrations were in the range of 1.5-2.5 Bq m^{-3} (40×10^{-16} - 70×10^{-16} Ci m^{-3}). Since 1983, the $^{239+240}$Pu concentrations in air have decreased significantly to approximately 0.2 µBq m^{-3} (5×10^{-16} Ci m^{-3}) or less. Because fallout actinides have been deposited fairly evenly throughout the northern hemisphere, the resulting activity concentration in samples of environmental media is extremely low. Nevertheless, if sufficiently large samples are processed, and a highly sensitive radio-analytical method is used, background concentrations of $^{239+240}$ Pu and other actinides resulting from fallout can be determined. Data produced from such analyses can be used to establish the present background level of $^{239-240}$Pu in environmental samples. This may serve to identify possible emissions from the WIPP site or other nuclear industry sources before concentrations reach levels that could pose health hazards. Such analyses also are valuable in testing the design of sampling equipment, the filter media, and

sample collection times. The mass concentration, $^{239-240}$ Pu concentration in air, and activity density on airborne solids at the WIPP site were in the ranges of 21-44 µg m^{-3}, 0.005-0.02 µBq m^{-3} (0.1 - 0.4×10^{-18} Ci m^{-3}) and 240-460 µBq g^{-1} (6×10^{-15} - 12×10^{-15} Ci g^{-1}), respectively, for the sampling periods in this study. The range of atmospheric $^{239+240}$Pu concentrations observed in this study is similar to that reported by Argonne National Laboratory.

Response of electret radon detectors to interference from ambient gamma radiation

The electret ionization chamber (EIC) is a commonly used detector for outdoor radon (Rn) measurements where long exposure times are required to measure low ambient natural background radon concentrations (Usman, Spitz and Lee, 1999). External gamma radiation must be monitored whenever the EIC is used to monitor Rn since it has been shown that the EIC is susceptible to discharge from cosmic and terrestrial gamma radiation exposure. Use of a constant gamma background correction factor for gamma radiation, rather than a voltage dependent correction factor suggested by this research, will introduce a systematic bias and result in values for the measured Rn concentration that consistently are lower than the true value. The most accurate estimate of gamma irradiation would be obtained by integrating the background exposure during Rn measurements using a calibrated ionization chamber to determine the total gamma exposure delivered to the EIC Rn detector. The EIC is a sensitive device for measuring the cumulative Rn concentration in the air. However, a voltage dependent correction factor must be applied to account for the discharge of the EIC produced by the natural and technologically-enhanced gamma radiation background, particularly when used near areas where gamma emitting radioactive materials are present.

In Vivo Measurement Sensitivity and Occurrence of Radionuclides in Residents of the Carlsbad, New Mexico Area

Following the commissioning of the CEMRC's *in vivo* monitoring facility, 81 volunteers were measured during July to September 1997. Figure 7-6 shows some volunteers participating in the LDBC counting. The measurements were conducted to identify internally deposited radionuclides in lungs and the whole body. Each examination lasted 1800 s and employed the measurement geometry described in the Internal Dosimetry program description. Chest wall thickness, used to correct for photon attenuation by tissue overlying the lungs, was estimated from physical parameters as described in the Internal Dosimetry Technical Basis Manual for the Center's Internal Dosimetry program. Spectral analyses were performed using the software package ABACOS® Plus from Canberra Industries. Radionuclides of interest (Table 7-2) were identified from a review of the WIPP Safety Analysis Report (DOE/WIPP-95-2065, 1995) and the Internal Dosimetry Technical Basis Document for the WIPP (DOE/WIPP-96- 2196, 1996). In addition, the naturally occurring radionuclide ^{40}K was also monitored.

Figure 7-6: Volunteers who participated in the LDBC

Table 7-2: Radionuclides of Interest for "Lie Down and Be Counted" Program

In-Vivo measurement type	Radionuclides of interest
Lung	^{241}Am, ^{144}Ce, ^{252}Cf, ^{244}Cm, ^{155}Eu, ^{237}Np, $^{238, 239, 240, 242}$Pu, $^{228, 232}$Th, $^{233, 234, 235, 238}$U
Whole Body	^{133}Ba, ^{140}Ba, ^{141}Ce, ^{58}Co, ^{60}Co, ^{51}Cr, ^{134,137}Cs, $^{152, 154, 155}$Eu, ^{59}Fe, $^{131, 133}$I, ^{192}Ir, ^{40}K, ^{54}Mn, $^{103, 106}$Ru, ^{125}Sb, ^{232}Th, ^{88}Y, ^{65}Zn, ^{95}Zr

On February 14, 2014 there was an underground radiation release event at the WIPP site resulting in a small release of radioactive contamination to the environment. In this context, the LDBC program's valuable information accumulated since 1997 to the present date can be divided into four significant categories, shown pictorially in Figure 7-7, and described as:

1) Baseline *in vivo* analyses on public volunteers, from 1997 to 1999, prior to the opening of the Waste Isolation Pilot Plant (WIPP).
2) *In vivo* analyses performed on public and contract personnel from 1999 up to the WIPP underground radiation release event on February 14, 2014.
3) *In vivo* analyses performed on public and contract personnel during the WIPP underground radiation release event from February 14, to June 30, 2014
4) *In vivo* analyses performed on public and contract personnel after the WIPP underground radiation release event from July 1, 2014 to Present.

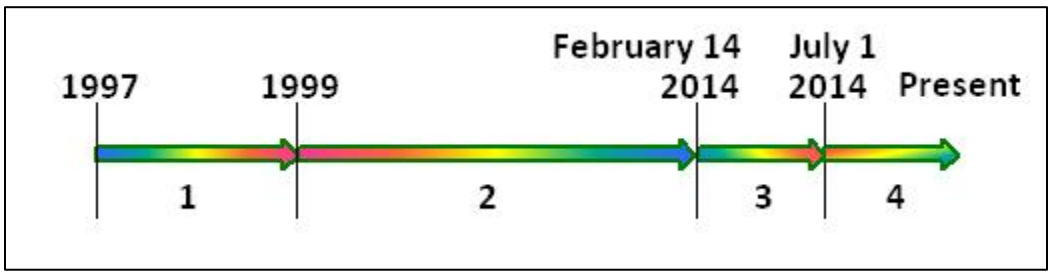


Figure 7-7: Time periods (not drawn to scale) of the LDBC *in vivo* radio-bioassay measurements of the public volunteers

The 2014 underground radiation release event report providing the evaluation of the LDBC results is available on-line: 2014 Release Event Chapter 7: Whole body Counting pp 109-118. http://www.cemrc.org/annual-reports/

Starting from 7/21/1997 to 12/31/2016, total of 1470 measurements were performed for the LDBC project. These measurements include baseline (first time counting), routine (second time on wards), and recounts (repeat count). At the time the Waste Isolation Pilot Plant (WIPP) began receiving waste on 3/26/1999, a total of 366[1] individuals had been measured using the *in vivo* protocol. This group of 366 measurements collected between 7/21/1997 to 3/26/1999 constituted the pre-operational baseline to which subsequent results are compared. Counts performed after the opening of the WIPP are considered to be a part of the operational monitoring phase of the WIPP environmental monitoring program.

Figure 7-8 shows the yearly number of male, female and total number of voluntary public participants counted thus far in the program period (7/21/1997 to 12/31/2016).

[1] This number was previously reported at 367 but that number included one test that was not part of the subject population.

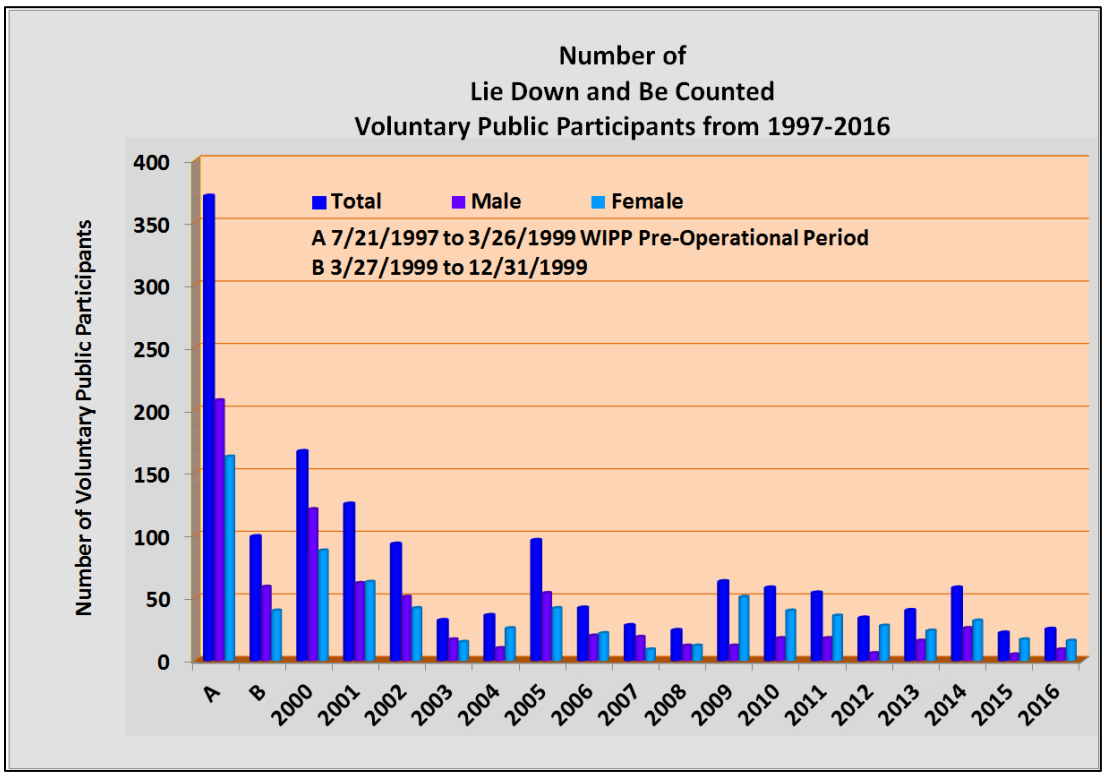


Figure 7-8: Number of LDBC voluntary public participants (total and by gender) counted during the period 1997-2016

In addition to the LDBC program, the CEMRC conducts *In Vivo* internal dosimetry counting services for radiation control workers in the area and has performed about 5044 counts which include baseline (in this context baseline means the first time counted at CEMRC), routine, recounts, exit, potential intake, and any other special counts on radiation trained workers in the region. Current contracts for internal dosimetry services include the WIPP and its management and operations contractor Nuclear Waste Partnership (NWP), Waste Control Specialists (WCS) of Andrews, TX; and Los Alamos National Laboratory (LANL), Carlsbad, NM; as well as CEMRC radiation workers.

Table 7-3 compares the LDBC demographic characteristics for every 5 years from 2001 to 2016 with the base line cohort study of 1997-1999. It also shows an increase of voluntary participation by Hispanics from 12.9% to 22.4% in the period 1999 - 2016. Per U.S. census data, the actual increase of the Hispanic population nationwide is 12.5% to 17.8% and the State of New Mexico is 42.1% to 48.5%. In addition, it is important to note that if the presence of a radionuclide is dependent on a subclass of interest (i.e. gender, ethnicity, etc.) valid population estimates can still be made by correcting for the proportion of under- or over-sampling for the particular subclass. With the exception of Hispanics, there are no noticeable changes for the rest of the demographic characteristics listed in Table 7-3.

For the purposes of the LDBC program, baseline monitoring is held constant and includes only the initial count of individuals made prior to March 26, 1999. Seven people were recounted during the baseline interval but these data are not reported in order to remain consistent with previous reports. Likewise, operational monitoring includes the counting of new volunteers and the recounting of previously measured participants that have occurred since the repository began accepting waste on March 27, 1999. Based on the data reported herein, there is no evidence of any increase in the frequency of detection of internally deposited radionuclides for citizens living within the vicinity of the WIPP since the WIPP began receiving radioactive waste.

As discussed in detail in the CEMRC 1998 Report and the work by Webb and Kirchner, 2000, the criterion, L_C, was used to evaluate whether a result exceeded background as the use of this criterion will result in a statistically inherent 5% false-positive error rate per pair-wise comparison (i.e. 5% of all measurements will be determined to be positive when there is no activity present in the person). The radionuclides being investigated by the CEMRC Internal Dosimetry program and their minimum detectable activities are listed in Tables 7-4 through 7-11 for the time period 2002 to 2017.

For the baseline measurement counts (N = 366), the percentage of results greater than L_C were consistent with a 5% random false-positive error rate, at the 95% confidence level (1% to 9%), for all radionuclides except ^{232}Th via the decay of ^{212}Pb, ^{235}U/^{226}Ra, ^{60}Co, ^{137}Cs, ^{40}K, ^{54}Mn, and ^{232}Th via the decay of ^{228}Ac (see for example Table 7-12 . As discussed in detail in the 1998 report, five of these radionuclides [^{232}Th via ^{212}Pb, ^{60}Co, ^{40}K, ^{54}Mn (^{228}Ac interference) and ^{232}Th (via ^{228}Ac)] are part of the shield-room background and positive detection is expected at low frequency. ^{40}K is a naturally occurring isotope of an essential biological element, so detection in all individuals is expected. ^{137}Cs and ^{235}U / ^{226}Ra are not components of the shielded room background and were observed at frequencies greater than the 95% confidence interval for the false positive error rate (discussed in more detail below).

For the operational monitoring counts (see Table 7-12, N = 1096), the percentage of results greater than L_C were consistent with baseline at a 95% confidence level (margin of error), except for ^{60}Co and ^{232}Th (via ^{228}Ac). For these radionuclides, the percentage of results greater than L_C decreased relative to the baseline. This would be expected for ^{60}Co, since the radionuclide has a relatively short half-life (5.2 years) and the content of ^{60}Co within the shield has decreased via decay by approximately 80% since the baseline phase of monitoring. Additionally, the differences in ^{232}Th (via ^{228}Ac) results between the baseline and operational monitoring phase were also observed in 2001 and 2002 and are likely due to the replacement of aluminum (tends to contain Th and U) in some of the detector cryostat components with those manufactured from low radiation background steel.

The percentage of results greater than L_C for $^{235}U/^{226}Ra$ (11 %) is significantly higher than the distribution-free confidence interval for a 5% random false-positive error rate. These data are not nearly as compelling as those for ^{137}Cs, but the large sample size of the current cohort tends to support the observed pattern. Although ^{235}U and ^{226}Ra cannot be differentiated via gamma spectroscopy, it is likely that the signal observed is the result of ^{226}Ra because the natural abundance of ^{226}Ra is much greater than that of ^{235}U. This finding shows the necessity of further research and procedural development needed to further enhance the detection capability of the CEMRC Internal Dosimetry counting facility.

Table 7-13 contains average, minimum, maximum, 1 standard deviation, standard error of detectable ^{40}K activity for total number of participants, separated by gender, listed for five time periods from 7/21/21997 to 12/31/2016.^{40}K results are positive for all participants through December 2016. Such results are expected since K is an essential biological element contained primarily in muscle. Therefore, ^{40}K, the radioactive isotope, is the theoretical constant fraction of all naturally occurring K. ^{40}K average value per person for males was significantly greater ($p < 0.0001$) than that of females. Since in general, males tend to have larger body sizes and greater muscle content than females.

Table 7-14 contains average, minimum, maximum, 1 standard deviation, and standard error of detectable ^{137}Cs activity for total number of participants, separated by gender, listed for five time periods from 7/21/1997 to 12/31/2016. The 1999 CEMRC Reports and Webb & Kirchner (2000), provide initial correlation studies of detectable ^{137}Cs with parameters like age, ethnicity, and European travel, and gender, consumption of wild game, nuclear medical treatments, radiation work history, and smoking.

Figure 7-9 shows the number of voluntary public participants, and the percentage of participants with detectable ^{40}K and ^{137}Cs activities, for four different periods during 1999-2016; providing a comparison with the results of baseline monitoring period of 1997-1999. CEMRC ID in vivo radiobioassay routinely measures the same radionuclide activities in the radiological workers of WIPP and other radioactive storage facilities. The most significant importance of these LDBC results over the past 20 years is the observation that there is no variation in the percentage of public participants with detectable levels of plutonium and americium. This suggests that there have been no observable Pu and Am effects from WIPP on the citizens living within a 100-mile radius of the WIPP repository including those measurements collected immediately following the 2014 underground radiation release event.

The LDBC program using the high sensitive and high efficiency Lung and Whole Body Counting system at the CEMRC, at Carlsbad, NM, funded by the DOE, is unique in its nature because such a facility and program are not available to the public anywhere else in the country. As mentioned previously, the LDBC program at the CEMRC is available to the residents around 100 miles of WIPP location 1) free of charge, 2) available throughout the year, 3) readily

accessible and can provide on-site information immediately about radiation contamination in the public in case of radiological accidents. The LDBC program is valuable not only to the local residents but also to the nation and the international research community.

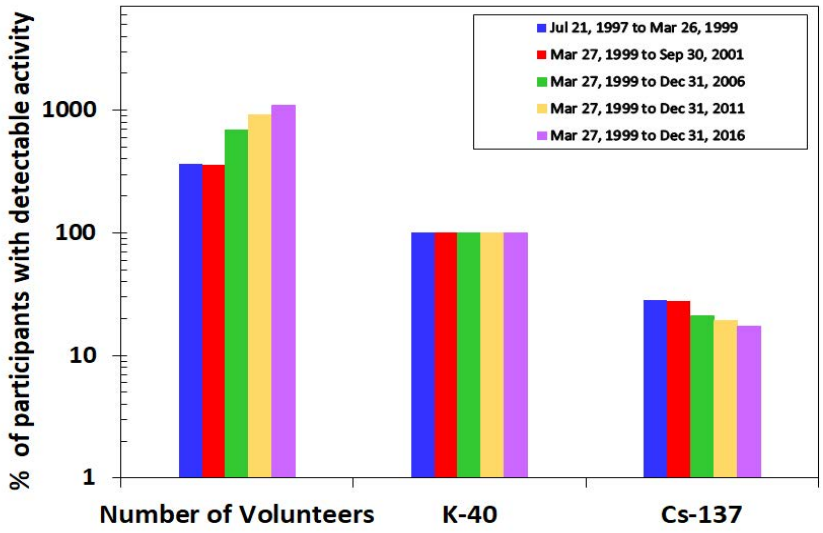


Figure 7-9: Number of voluntary public participants, and the percentage of voluntary public participants with detectable ^{40}K and ^{137}Cs activities

Research studies conducted using the *In-Vivo* lung and whole body counting system and LDBC cohort studies

The CEMRC began the construction and procurement of a lung and whole-body counting system during the winter of 1996. Through a competitive and technical bid process, Canberra Industries was awarded the contract for the fabrication of the instrument in collaboration with CEMRC scientists. In addition, new technology was developed and tested during the manufacturing of the instrument, including (1) the determination of the appropriate detector thickness for the CEMRC application, (2) the production of 20 mm thick, 3800 mm^2 lung counting detectors with broad photon energy response (BEGe, 9-2000 keV), (3) electronic modifications to reduce low energy noise from cosmic ray interactions in the detectors, (4) an optimal alignment for Canberra cryostats to improve lung counting efficiency, and (5) the development and evaluation of a 20 mm thick, 5000 mm^2 BEGe detector for lung counting.

The collaboration between CEMRC and the Rocky Flats Nuclear Facility (RFETS) has resulted in technology that has improved the sensitivity for the measurement of radionuclides deposited in lungs. Reliable detectors with broad energy response have been produced at a

thickness of 20 mm and surface areas of 3800 and 5000 mm^2. By reducing detector thickness, detector background has been reduced without sacrificing counting efficiency at energies below 200 keV. The cosmic overload ground circuitry significantly reduced detector background at energies below 40 keV with a 47% reduction for the plutonium region of interest (17 keV). Optimal alignment of Act II cryostats improved lung counting efficiency for plutonium and americium. For the sake of comparison, the minimum detectable amount (MDA) for various radionuclides deposited in lungs is provided in Table 7-4. These values of MDA include all the technology improvements described herein. The MDA for various radionuclides were calculated using ANSI N13.30 methodology and were derived from the Humanoid Torso phantom with the chest plate only. This method does not provide a good MDA for real people since human chest walls are typically much thicker. However, this does provide a calculation method that is easily repeatable at other facilities and is independent of chest plate overlay thickness and composition.

Citizen volunteers from the Carlsbad, New Mexico area were monitored for internally deposited nuclides through a project entitled 'Lie Down and Be Counted'. This project is provided as an outreach service to the public to support education about naturally occurring and man-made radioactivity present in people and the environment prior to the opening of the Waste Isolation Pilot Plant (WIPP). The bioassay measurements consisted of a lung and whole-body count prior to their bioassay, each subject completed a lifestyle questionnaire which included questions regarding their age, sex, weight, height, ethnicity, occupation, foreign travel, wild game consumption, smoking habits and any nuclear medicine procedures. Since a majority of these radio nuclides were not detectable in local residents, a primary focus of the study was to evaluate the variability of human background and the implications with respect to measurement sensitivity.

The results consisted of cohort demographics, background rates variability, minimum detectable amount, the usage of the criterion Lc to decide whether a result is greater than background, 5% false positive and false negative occurrence of radionuclide in the lung and whole body, evaluation of false negative error rate using the region of interest (ROI) algorithm, demographic characteristics associated with the occurrence of ^{137}Cs in the local residents.

One of the most contemplated subjects in life sciences research involves low dose radiation effects on the living, especially doses delivered at low rates characteristic of most human exposures to environmental levels of radioactivity. Naturally occurring radioactive sources internal to the human body provide the closest exposure to high linear energy transfer (LET) radiation from alpha-radionuclides. The most important short-lived radioactive sources of interest appear to be those derived from radon and its immediate decay products such as ^{210}Pb which is a part of the chain of radon decay products. One of the latest research interests in cranium internal dosimetry involves the study of ^{210}Pb activity by *In Vivo* gamma-ray spectrometry, especially considering its relation to Alzheimer's disease (AD), Parkinson's disease (PD) and multiple sclerosis (MS).

Because of its capabilities to detect minute levels of radiation, *In Vivo* internal dosimetry counting is very sensitive to background radiation. Thus, the detection sensitivity of a surface *In Vivo* counting facility, built with existing low background counting concepts and techniques, can be further improved by developing an *In Vivo* low background facility underground whereby the earth acts as an added shield in terms of reducing the amount of background radiation. Reliable detection of the radioactivity of trans-uranium (TRU) radioisotopes, especially Plutonium isotopes ($^{238, 240, 242}$Pu) and Americium (^{241}Am) is an ongoing requirement for Internal Dosimetry (ID) considerations for radiological workers handling TRU waste, generated at the Department of Energy (DOE) facilities. These radioisotopes emit high LET alpha radiations which become hazardous when present internally in the body. Urine samples collected from the radiation workers can be analyzed with high sensitivity for ^{241}Am and the Pu isotopes by radiochemical techniques. The current in-vivo gamma analyses could not compete with radiochemical separation processes because of the low intensities and low energies of the gamma rays emitted from the TRU isotopes.

The Internal Dosimetry facility is in a unique position to enhance its Lung and Whole Body (L&WBC) counting facility capability by developing a high sensitivity counter taking advantage of the underground infrastructure at the WIPP. The advantage is that the background can be reduced by a factor of three and thus sensitivity can be enhanced at the WIPP underground science Laboratory.

Research is on-going with minimum available resources for the development of a reliable non-invasive non-destructive *In-Vivo* method for the detection of the activities of the TRU isotopes at sub-nano curie level, or determination of ^{210}Pb at pico-curie level in a cranium.

The first step is to measure the minimum detection activity using minimum available resources such as HPGe detector, a volunteer and an existing shielded chamber at 2150' below ground at WIPP location.

Internal dosimetry of ^{210}Pb in the cranium deals with the determination of the amount of energy deposited in tissue by ^{210}Pb radiations within the cranium. ^{210}Pb in the human cranium was monitored by in vivo counting in a low background facility 640 m (2100 feet) underground with a Ge γ-ray detector having a beryllium window. The minimum detectable activity (MDA) was established with this system to be 0.2 Bq (5 pCi) in 25 hour counting time with a 15 mm diameter and 7 mm thick Ge detector, having a beryllium window of thickness 0.08 mm, in contact with the cranium just above the ear adjacent to the temple region. In order to establish an MDA of 0.004 Bq (0.1 pCi) with this system, the limitation arising from the ambient radon level at 10 Bq/m^3 was investigated.

The second step is to identify the transmitted component arising from the ^{40}K, 1461 keV incident photon flux on site at the WIPP underground location.

One of the further considerations in the present work, while setting up a low background whole body counter underground at the WIPP is to reduce the background in the energy region of interest below 100 keV. The goal of the present work is to determine the adequacy of a chamber located underground at WIPP, of dimensions 1.83 m×1.22 m at the base, 1.83 m high, with 15 cm thick pre-world-war II steel shielding. The objective of the present work is to estimate the transmitted photon flux into this chamber for setting up the low background WBC. The transmitted photon flux is simulated with the GEANT4 code for an incident photon flux consisting only of 1461 keV photons. The results are discussed with respect to a detector of choice for detecting < 50 mBq emitting photons in the energy region below 100 keV.

The third step was to estimate the interfering background recorded in the energy regions of interest (ROI), that represent the detection of trans-uranium (TRU) isotopes deposited in the lungs, in the presence of ^{40}K internal to the human body. GEANT simulations were carried out for a point source without and with the shielding, and for a BOMAB phantom in the shielded whole body counting chamber underground at the WIPP.

The objective is to find a solution for the interference arising from 1461 keV photons emitted by ^{40}K in natural K internal to the human body in the detection of ^{241}Am and ^{210}Pb activities at the level of 37 mBq (1 pCi). The response of a broad energy Ge (BEGe) reference crystal to 1461 keV photons was simulated using GEANT4 code. Simulations were performed for a point source without and with shielding, as well as for a Bottle Manikin Absorption (BOMAB) phantom in the shielded whole-body counting chamber. The facility is located underground at the Waste Isolation Pilot Plant, Carlsbad, NM, USA. The simulation results were discussed with regards to the interference in detecting the ^{241}Am and ^{210}Pb at the level of 37 mBq (1 pCi). The specific conclusion is that the interference counts from ^{40}K activity at the natural levels present in the human body, in typical clinical settings, were found to be greater than the ^{210}Pb and ^{241}Am signal counts. These counts were from 37 mBq (1 pCi), when a 38.1 mm diameter, 25.4 mm thick BEGe reference crystal was used. Our solution for minimizing the interference to the desired precision at the specified levels was found by sacrificing the broad energy response of the counting system.

Table 7-3: Demographic Characteristics of the "Lie Down and Be Counted" Population Sample groups of 1999, 2001, 2006, 2011 and 2016

Characteristic		Voluntary Public Participants				
		1999 9/21/97-9/30/99	**2001 9/21/97-9/30/01**	**2006 3/27/99-12/31/06**	**2011 3/27/99-12/31/11**	**2016 3/27/99-12/31/16**
Gender	Male	56.6 (52.2 to 61.9%)	53.4% (48.0 to 58.8%)	49.9% (46.4 to 53.4%)	46.5% (43.3 to 49.6%)	45.1% (42.1 to 48.0%)
	Female	43.4% (38.6 to 48.3%)	46.6% (41.2 to 52.0%)	50.1% (46.6 to 53.6%)	53.5% (50.4 to 56.7%)	54.9% (52.0 to 57.9%)
Ethnicity	Hispanic	12.9% (9.5 to 16.3%)	14.1% (10.3 to 18.0%)	15.2% (12.7 to 17.7%)	20.2% (17.7 to 22.7%)	22.4% (19.9 to 24.8%)
	All others	87.1% (83.3 to 90.9%)	83.1% (79.0 to 87.4%)	83.7% (81.2 to 86.3%)	79.8% (77.3 to 82.3%)	77.6% (75.2 to 80.1%)
Age 65 years or over		25.0% (20.0 to 30.0%)	29.9% (24.9 to 35.0%)	26.9% (24.2 to 29.5%)	26.1% (23.3 to28.8%)	33.3% (30.5 to 36.1%)
Currently or previously classified as a radiation worker		4.9% (2.7 to 7.0%)	5.4 % (3.0 to 7.9%)	7.4% (5.8 to 8.9%)	7.6% (6.0 to 9.3%)	10.1% (8.3 to 11.9%)
Consumption of wild game within 3 months prior to count		15.3% (11.7 to 18.9%)	18.1 % (13.8 to 22.2%)	21.7% (19.2 to 24.2%)	20.7% (18.2 to 23.2%)	23.3% (20.8 to 25.8%)
Medical treatment other than X-rays using radionuclides		9.0% (6.1 to 11.9%)	8.0% (5.1 to 11.0%)	7.6% (6.0 to 9.2%)	7.5% (5.9 to 9.1%)	5.9% (4.5 to 7.3%)
European/Japan travel within 2 years prior to the count		3.9% (1.9 to 5.8%)	4.4% (2.1 to 6.7%)	5.6% (4.2 to 6.9%)	4.2% (2.9 to 5.5%)	4.7% (3.5 to 6.0%)
Current Smoker		14.6% (10.9 to 18.2%)	14.8 % (11.0 to 18.7%)	13.5% (11.4 to 15.5%)	15.8% (13.5 to 18.1%)	14.0 % (11.9 to 16.0%)

*Values in parentheses are margin of error

Table 7-3: Demographic Characteristics of the "Lie Down and Be Counted" Population Sample groups of 1999, 2001, 2006, 2011 and 2016 (continued)

Characteristic		2000[a]		2010[b]		2016[c] estimates	
		NM	US	NM	US	NM	US
Gender	Male	49.20%	49.10%	49.40%	49.20%	49.50%	49.20%
	Female	50.80%	50.90%	50.60%	50.80%	50.50%	50.80%
Ethnicity	Hispanic	42.10%	12.50%	46.30%	16.30%	48.50%	17.80%
	All others	57.90%	87.50%	53.70%	83.70%	51.50%	82.20%
Age 65 years or over		11.70%	12.40%	13.20%	13.00%	16.50%	15.20%
Currently or previously classified as a radiation worker		NA	NA	NA	NA	NA	NA
Consumption of wild game within 3 months prior to count		NA	NA	NA	NA	NA	NA
Medical treatment other than X-rays using radionuclides		NA	NA	NA	NA	NA	NA
European/Japan travel within 2 years prior to the count		NA	NA	NA	NA	NA	NA
Current Smoker		N/A	N/A	N/A	NA	16[+]% - 19%[e]	15.1%[f]

[a] 2000 Census (https://www.census.gov/census2000/states/us.html)
(https://factfinder.census.gov/faces/tablwww.census.gov/census2000/states/us.html)
(https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=CF)
(Web accessed on 11/1/2017)

[b] 2010 Census (https://www.census.gov/2010census/data/)
(https://www.census.gov/prod/cen2010/briefs/c2010br-03.pdf)
(https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=CF')
(Web accessed on 11/1/2017)

[c] 2016 Census estimates (https://www.census.gov/quickfacts/fact/table/US/PST045216)
(https://www.census.gov/quickfacts/fact/table/NM,US/PST045216#viewtop)
(https://www.census.gov/quickfacts/NM)
(Web accessed on 11/1/2017)

[d] margin of error – The margin of error The margin of error represents the 95% confidence interval of the observed proportion; under complete replication of this experiment, one would expect the confidence interval to include the true population proportion 95% of the time if the sample was representative of the true population.

[e] (https://www.cdc.gov/vitalsigns/tobaccouse/smoking/infographic.html)

[f] (https://www.cdc.gov/tobacco/data statistics/fact sheets/index.htm)

Table 7-4: Minimum Detectable Activities (Calibration Using 4 Lung detectors)

		Chest Wall Thickness (CWT) 1.6 cm*				
Radionuclide	**Energy (keV)**	**2016-2017**	**2011-2012**	**2006-2007**	**Average MDA (nCi)**	**Std. Dev 1σ (nCi)**
Am-241	59.50	0.19	0.17	0.18	0.18	0.01
Ce-144	133.50	0.47	0.48	0.47	0.48	0.01
Cf-252	19.20	17.54	19.34	16.41	18.37	1.16
Cm-244	18.10	16.37	17.43	15.35	16.77	0.76
Eu-155	105.30	0.28	0.27	0.28	0.27	0.01
Np-237	86.50	0.51	0.46	0.50	0.47	0.02
Pu-238	17.10	18.38	17.66	16.38	17.66	0.88
Pu-239	17.10	45.72	43.94	40.75	43.95	2.18
Pu-240	17.10	17.96	17.26	16.01	17.27	0.86
Pu-242	17.10	21.67	20.82	19.31	20.83	1.03
Ra-226	186.10	1.67	1.79	1.68	1.72	0.08
Th-232 via Pb-212	238.60	0.155	0.149	0.157	0.150	0.003
Th-232	59.00	34.71	32.03	33.96	33.34	0.97
Th-232 via Th-228	84.30	4.98	4.46	5.04	4.73	0.21
U-233	440.30	0.67	0.65	0.66	0.65	0.02
U-235	185.70	0.103	0.111	0.104	0.106	0.005
Natural U via Th-234	63.30	1.67	1.51	1.59	1.56	0.07

*Average and Standard Deviation are from 2006-2007 to 2016-2017, values of all the years inclusive, not just the values shown for the three periods in the table

Table 7-5: Minimum Detectable Activities (Calibration Using 4 Lung detectors)

		Chest Wall Thickness (CWT) 2.2 cm*				
Radionuclide	**Energy (keV)**	**2016-2017**	**2011-2012**	**2006-2007**	**Average MDA (nCi)**	**Std. Dev 1σ (nCi)**
Am-241	59.50	0.23	0.23	0.23	0.23	0.01
Ce-144	133.50	0.57	0.56	0.56	0.56	0.01
Cf-252	19.20	34.97	35.17	32.73	34.69	1.02
Cm-244	18.10	35.21	35.55	32.95	34.83	1.22
Eu-155	105.30	0.343	0.332	0.338	0.333	0.005
Np-237	86.50	0.62	0.60	0.61	0.60	0.01
Pu-238	17.10	42.83	41.60	38.20	40.97	2.01
Pu-239	17.10	106.57	103.50	95.05	101.93	4.99
Pu-240	17.10	41.87	40.66	37.34	40.04	1.96
Pu-242	17.10	50.51	49.05	45.05	48.31	2.36
Ra-226	186.10	1.96	1.92	1.95	1.93	0.02
Th-232 via Pb-212	238.60	0.182	0.173	0.183	0.177	0.004
Th-232	59.00	42.93	42.18	41.87	42.67	0.77
Th-232 via Th-228	84.30	6.15	5.92	6.16	6.04	0.12
U-233	440.30	0.78	0.76	0.76	0.76	0.02
U-235	185.70	0.121	0.119	0.121	0.120	0.001
Natural U via Th-234	63.30	2.07	2.00	2.13	2.02	0.05

*Average and Standard Deviation are from 2006-2007 to 2016-2017, values of all the years inclusive, not just the values shown for the three periods in the table

Table 7-6: Minimum Detectable Activities (Calibration Using 4 Lung detectors)

		Chest Wall Thickness (CWT) 3.01 cm*				
Radionuclide	**Energy (keV)**	**2016-2017**	**2011-2012**	**2006-2007**	**Average MDA (nCi)**	**Std. Dev 1σ (nCi)**
Am-241	59.50	0.31	0.30	0.29	0.30	0.01
Ce-144	133.50	0.72	0.71	0.69	0.71	0.01
Cf-252	19.20	84.48	85.66	78.83	82.86	3.25
Cm-244	18.10	93.20	95.16	87.42	91.47	3.90
Eu-155	105.30	0.44	0.43	0.43	0.43	0.01
Np-237	86.50	0.81	0.78	0.78	0.79	0.02
Pu-238	17.10	126	123	113	120	6
Pu-239	17.10	312	305	280	297	15
Pu-240	17.10	123	120	110	117	6
Pu-242	17.10	148	145	133	141	7
Ra-226	186.10	2.40	2.37	2.35	2.37	0.03
Th-232 via Pb-212	238.60	0.223	0.214	0.222	0.220	0.003
Th-232	59.00	57.05	56.17	54.88	56.99	1.62
Th-232 via Th-228	84.30	7.99	7.73	7.93	7.94	0.24
U-233	440.30	0.95	0.92	0.91	0.92	0.02
U-235	185.70	0.148	0.147	0.145	0.147	0.003
Natural U via Th-234	63.30	2.73	2.67	2.54	2.66	0.07

*Average and Standard Deviation are from 2006-2007 to 2016-2017, values of all the years inclusive, not just the values shown for the three periods in the table

Table 7-7: Minimum Detectable Activities (Calibration using 4 Lung detectors)

		Chest Wall Thickness (CWT) 3.33 cm*				
Radionuclide	**Energy (keV)**	**2016-2017**	**2011-2012**	**2006-2007**	**Average MDA (nCi)**	**Std. Dev 1σ (nCi)**
Am-241	59.50	0.34	0.34	0.33	0.34	0.01
Ce-144	133.50	0.79	0.78	0.76	0.78	0.01
Cf-252	19.20	121	123	113	118	5
Cm-244	18.10	139	142	129	135	7
Eu-155	105.30	0.49	0.48	0.47	0.48	0.006
Np-237	86.50	0.90	0.88	0.86	0.89	0.02
Pu-238	17.10	195	192	174	185	10
Pu-239	17.10	485	477	433	459	25
Pu-240	17.10	191	187	170	180	10
Pu-242	17.10	230	226	205	218	12
Ra-226	186.10	2.60	2.58	2.54	2.57	0.03
Th-232 via Pb-212	238.60	0.243	0.233	0.240	0.237	0.005
Th-232	59.00	63.90	63.19	61.17	64.07	2.14
Th-232 via Th-228	84.30	8.90	8.68	8.78	8.90	0.31
U-233	440.30	1.02	1.00	0.98	1.00	0.02
U-235	185.70	0.161	0.160	0.157	0.159	0.001
Natural U via Th-234	63.30	3.05	2.99	2.83	2.99	0.09

*Average and Standard Deviation are from 2006-2007 to 2016-2017, values of all the years inclusive, not just the values shown for the three periods in the table

Table 7-8 Minimum Detectable Activities (Calibration using 4 Lung detectors)

		Chest Wall Thickness (CWT) 4.18 cm*				
Radionuclide	**Energy (keV)**	**2016-2017**	**2011-2012**	**2006-2007**	**Average MDA (nCi)**	**Std. Dev 1σ (nCi)**
Am-241	59.50	0.46	0.46	0.44	0.46	0.02
Ce-144	133.50	1.01	1.01	0.95	1.01	0.03
Cf-252	19.20	313	320	290	301	20
Cm-244	18.10	396	409	369	383	25
Eu-155	105.30	0.64	0.63	0.61	0.64	0.02
Np-237	86.50	1.19	1.18	1.13	1.19	0.05
Pu-238	17.10	625	617	556	585	37
Pu-239	17.10	1554	1535	1382	1456	93
Pu-240	17.10	610	603	543	572	37
Pu-242	17.10	736	727	655	690	44
Ra-226	186.10	3.24	3.23	3.11	3.21	0.06
Th-232 Via Pb-212	238.60	0.303	0.293	0.297	0.299	0.007
Th-232	59.00	86.32	86.22	81.63	87.49	4.10
Th-232 via Th-228	84.30	11.84	11.65	11.52	11.98	0.64
U-233	440.30	1.26	1.23	1.19	1.23	0.02
U-235	185.70	0.200	0.200	0.192	0.199	0.005
Natural U via Th-234	63.30	4.11	4.07	3.76	4.07	0.17

*Average and Standard Deviation are from 2006-2007 to 2016-2017, values of all the years inclusive, not just the values shown for the three periods in the table

Table 7-9: Minimum Detectable Activities (Calibration Using 4 Lung detectors)

		Chest Wall Thickness (CWT) 5.10 cm				
Radionuclide	Energy (keV)	2016-2017	2011-2012	2006-2007	Average MDA (nCi)	Std. Dev 1σ (nCi)
Am-241	59.50	0.64	0.65	0.60	0.65	0.03
Ce-144	133.50	1.32	1.33	1.23	1.32	0.05
Cf-252	19.20	874	903	809	833	75
Cm-244	18.10	1238	1284	1146	1179	99
Eu-155	105.30	0.86	0.86	0.80	0.86	0.04
Np-237	86.50	1.62	1.62	1.52	1.64	0.10
Pu-238	17.10	2190	2197	1952	2040	159
Pu-239	17.10	5448	5465	4857	5075	396
Pu-240	17.10	2140	2147	1908	1994	156
Pu-242	17.10	2582	2590	2302	2405	188
Ra-226	186.10	4.11	4.11	3.88	4.08	0.11
Th-232 via Pb-212	238.60	0.385	0.375	0.372	0.384	0.012
Th-232	59.00	119.67	120.79	111.39	122.52	7.59
Th-232 via Th-228	84.30	16.12	16.03	15.46	16.54	1.20
U-233	440.30	1.57	1.54	1.48	1.54	0.04
U-235	185.70	0.254	0.255	0.240	0.251	0.006
Natural U via Th-234	63.30	5.67	5.69	5.12	5.69	0.32

*Average and Standard Deviation are from 2006-2007 to 2016-2017,
values of all the years inclusive, not just the values shown for the three periods in the Table.

Table 7-10 Minimum Detectable Activities (Calibration Using 4 Lung detectors)

		Chest Wall Thickness (CWT) 6.0 cm				
Radionuclide	**Energy (keV)**	**2016-2017**	**2011-2012**	**2006-2007**	**Average MDA (nCi)**	**Std. Dev 1σ (nCi)**
Am-241	59.50	0.88	0.90	0.81	0.90	0.06
Ce-144	133.50	1.72	1.75	1.57	1.73	0.08
Cf-252	19.20	2393	2488	2199	2251	255
Cm-244	18.10	3746	3936	3477	3546	372
Eu-155	105.30	1.14	1.15	1.06	1.16	0.08
Np-237	86.50	2.19	2.21	2.02	2.24	0.18
Pu-238	17.10	7502	7588	6685	6923	643
Pu-239	17.10	18666	18880	16634	17224	1601
Pu-240	17.10	7333	7417	6535	6767	629
Pu-242	17.10	8846	8948	7883	8163	759
Ra-226	186.10	5.19	5.22	4.82	5.15	0.18
Th-232 via Pb-212	238.60	0.486	0.477	0.463	0.488	0.021
Th-232	59.00	164.80	167.59	151.30	170.39	13.13
Th-232 via Th-228	84.30	21.78	21.93	20.59	22.66	2.12
U-233	440.30	1.96	1.92	1.81	1.93	0.07
U-235	185.70	0.321	0.323	0.298	0.318	0.012
Natural U via Th-234	63.30	7.77	7.86	6.92	7.89	0.56

*Average and Standard Deviation are from 2006-2007 to 2016-2017, values of all the years inclusive, not just the values shown for the three periods in the Table.

Table 7-11 Minimum Detectable Activities – Whole Body
(Calibration using 4 Lung and 4 Whole Body detectors)

		Chest Wall Thickness (CWT) 6.0 cm*				
Radionuclide	**Energy (keV)**	**2016-2017**	**2011-2012**	**2006-2007**	**Average MDA (nCi)**	**Std. Dev 1σ (nCi)**
Am-241	59.50	0.88	0.90	0.81	0.90	0.06
Ce-144	133.50	1.72	1.75	1.57	1.73	0.08
Cf-252	19.20	2393	2488	2199	2251	255
Cm-244	18.10	3746	3936	3477	3546	372
Eu-155	105.30	1.14	1.15	1.06	1.16	0.08
Np-237	86.50	2.19	2.21	2.02	2.24	0.18
Pu-238	17.10	7502	7588	6685	6923	643
Pu-239	17.10	18666	18880	16634	17224	1601
Pu-240	17.10	7333	7417	6535	6767	629
Pu-242	17.10	8846	8948	7883	8163	759
Ra-226	186.10	5.19	5.22	4.82	5.15	0.18
Th-232 via Pb-212	238.60	0.486	0.477	0.463	0.488	0.021
Th-232	59.00	164.80	167.59	151.30	170.39	13.13
Th-232 via Th-228	84.30	21.78	21.93	20.59	22.66	2.12
U-233	440.30	1.96	1.92	1.81	1.93	0.07
U-235	185.70	0.321	0.323	0.298	0.318	0.012
Natural U via Th-234	63.30	7.77	7.86	6.92	7.89	0.56

*Average and Standard Deviation are from 2002-2003 to 2016-2017, values of all the years inclusive, not just the values shown for the four periods in the Table.

Table 7-12: Lie Down and Be Counted (results through December 31, 2016)

Radionuclide	*In-Vivo* count type	Baseline counts (N=366) % of results ≥ L_C[b]	Operational monitoring counts (N=1096) % of results ≥ L_C[b]
^{241}Am	Lung	5.2 (4.0 to 6.4)	4.47 (3.25 to 5.69)
^{144}Ce	Lung	4.6 (3.5 to 5.7)	4.47 (3.25 to 5.69)
^{252}Cf	Lung	4.1 (3.1 to 5.1)	5.66 (4.29 to 7.02)
^{244}Cm	Lung	5.7 (4.5 to 7.0)	5.02 (3.73 to 6.31)
^{155}Eu	Lung	7.1 (5.8 to 8.4)	5.11 (3.81 to 6.41)
^{237}Np	Lung	3.6 (2.6 to 4.5)	3.65 (2.54 to 4.76)
^{210}Pb	Lung	4.4 (3.3 to 5.4)	6.39 (4.94 to 7.83)
Plutonium isotopes	Lung	5.7 (4.5 to 7.0)	5.29 (3.97 to 6.62)
^{232}Th[d] via ^{212}Pb	Lung	34.2 (31.7 to 36.6)	31.48 (28.73 to 34.23)
^{232}Th	Lung	4.9 (3.8 to 6.0)	5.38 (4.05 to 6.72)
^{232}Th via ^{228}Th	Lung	4.1 (3.1 to 5.1)	4.56 (3.33 to 5.8)
^{233}U	Lung	5.7 (4.5 to 7.0)	9.12 (7.42 to 10.83)
^{235}U/^{226}Ra	Lung	10.7 (9.0 to 12.3)	10.95 (9.1 to 12.8)
Natural U via ^{234}Th	Lung	5.2 (4.0 to 6.4)	5.66 (4.29 to 7.02)
^{133}Ba	Whole Body	3.6 (2.6 to 4.5)	3.10 (2.08 to 4.13)
^{140}Ba	Whole Body	5.2 (4.0 to 6.4)	4.11 (2.93 to 5.28)
^{141}Ce	Whole Body	3.6 (2.6 to 4.5)	4.74 (3.49 to 6)
^{58}Co	Whole Body	4.4 (3.3 to 5.4)	3.38 (2.31 to 4.45)
^{60}Co[d]	Whole Body	54.6 (52.0 to 57.2)	22.81 (20.33 to 25.29)
^{51}Cr	Whole Body	5.7 (4.5 to 7.0)	4.29 (3.09 to 5.49)
^{134}Cs	Whole Body	1.6 (1.0 to 2.3)	2.65 (1.7 to 3.6)
^{137}Cs	Whole Body	28.4 (26.1 to 30.8)	17.43 (15.18 to 19.67)
^{152}Eu	Whole Body	7.4 (6.0 to 8.7)	5.75 (4.37 to 7.13)
^{154}Eu	Whole Body	3.8 (2.8 to 4.8)	3.38 (2.31 to 4.45)
^{155}Eu	Whole Body	3.8 (2.8 to 4.8)	3.47 (2.38 to 4.55)
^{59}Fe	Whole Body	3.8 (2.8 to 4.8)	5.84 (4.45 to 7.23)
^{131}I	Whole Body	5.2 (4.0 to 6.4)	4.2 (3.01 to 5.38)
^{133}I	Whole Body	3.3 (2.3 to 4.2)	4.01 (2.85 to 5.18)
^{192}Ir	Whole Body	4.1 (3.1 to 5.1)	4.11 (2.93 to 5.28)
^{40}K	Whole Body	100.0 (100.0 to 100.0)	100 (100 to 100)
^{54}Mn[d]	Whole Body	12.3 (10.6 to 14.0)	12.32 (10.37 to 14.26)
^{103}Ru	Whole Body	2.2 (1.4 to 3.0)	1.82 (1.03 to 2.62)
^{106}Ru	Whole Body	4.4 (3.3 to 5.4)	4.47 (3.25 to 5.69)
^{125}Sb	Whole Body	5.2 (4.0 to 6.4)	4.38 (3.17 to 5.59)
^{232}Th via ^{228}Ac	Whole Body	34.7 (32.2 to 37.2)	25.36 (22.79 to 27.94)
^{88}Y	Whole Body	7.7 (6.3 to 9.0)	6.48 (5.02 to 7.94)

Table 7-13: Average, 1 standard deviation, standard error, minimum, maximum, of detectable ^{40}K activity for total number of public participants, separated by gender

K-40	Number of participants	Average (Bq)	Standard Deviation (Bq)	Standard error (Bq)	Minimum (Bq)	Maximum (Bq)
	7/21/1997 to 3/26/1999					
Female	163	2314	509	40	1166	3615
Male	209	3629	628	43	2212	5559
Total	372	3053	872	45	1166	5559
	3/27/1999 to 12/31/2001					
Female	191	1726	311	23	1027	2639
Male	200	2817	587	42	1274	4749
Total	391	2284	722	37	1027	4749
	1/1/2002 to 12/31/2006					
Female	148	1799	374	31	996	2975
Male	151	2774	521	42	1326	4271
Total	299	2292	666	39	996	4271
	1/1/2007 to 12/31/2011					
Female	146	1778	296	24	925	2691
Male	81	2761	459	51	1739	4096
Total	227	2129	595	39	925	4096
	1/1/2012 to 12/31/2016					
Female	117	1668	412	38	551	2816
Male	62	2643	466	59	1696	3964
Total	179	2006	551	3964	551	3964

Table 7-14: Average, 1 standard deviation, standard error, minimum, maximum, of detectable ^{137}Cs activity for total number of public participants, separated by gender

Cs-137	Number of participants	Average (Bq)	Standard Deviation (Bq)	Standard error (Bq)	Minimum (Bq)	Maximum (Bq)
	7/21/1997 to 3/26/1999					
Female	33	9.04	2.95	0.51	5.62	20.12
Male	72	11.35	7.68	0.90	6.06	63.08
Total	105	10.62	6.64	0.65	5.62	63.08
	3/27/1999 to 12/31/2001					
Female	30	8.42	2.81	0.51	4.93	17.43
Male	59	10.17	6.48	0.84	5.26	45.69
Total	89	9.58	5.56	0.59	4.93	45.69
	1/1/2002 to 12/31/2006					
Female	18	8.68	2.63	0.62	5.39	13.84
Male	39	12.33	14.68	2.35	5.15	77.49
Total	57	11.18	12.30	1.63	5.15	77.49
	1/1/2007 to 12/31/2011					
Female	13	8.83	3.20	0.89	5.80	16.30
Male	19	9.29	2.94	0.67	6.15	16.11
Total	32	9.10	3.00	0.53	5.80	16.30
	1/1/2012 to 12/31/2016					
Female	8	30.74	4.56	128.29	43.68	15.44
Male	5	8.70	6.17	11.69	2.08	0.93
Total	13	22.26	4.56	128.29	35.20	9.76

CHAPTER 8

Analysis of Volatile Organic Compounds, Hydrogen and Methane

The WIPP Hazardous Waste Treatment Facility (HWTF) permit, Attachment N, issued by the New Mexico Environment Department (NMED) under the Resource Conservation and Recovery Act (RCRA), mandates the monitoring of volatile organic compound (VOC) emissions from mixed waste that may be entrained in the ambient air from the WIPP underground hazardous waste disposal units (HWDUs) to assure that VOC concentrations do not exceed regulatory limits, during or after disposal. Ten target VOCs are actively monitored as they represent 99% risk to safety due to air emissions, and any other compounds consistently detected in air samples may be added to the list of compounds of interest. The HWTF permit, Attachment N1 describes the monitoring plan for hydrogen and methane generated from underground panels.

VOC monitoring is conducted in accordance with the *"Volatile Organic Compound Monitoring Plan (WP 12-VC.01)",* prepared by the Nuclear Waste Partnership LLC (NWP), formerly Washington TRU Solutions (WTS). Hydrogen and Methane monitoring is performed in accordance with the *"Hydrogen and Methane Monitoring Plan (WP 12-VC.03)".* As described in these plans, NWP personnel collect ambient air samples in six liter passivated canisters and deliver them to the CEMRC for analysis in weekly batches.

The CEMRC first began analysis of samples for the Confirmatory VOCs Monitoring Plan in April 2004. The program was established and successfully audited by the WTS QA group prior to the acceptance of actual samples and has since been audited at yearly intervals. Initially, the CEMRC had one 6890/5973 Hewlett Packard (now Agilent) gas chromatograph/mass spectrometer (GC/MS) which had previously been used by the Los Alamos National Laboratory (LANL). The CEMRC purchased an Entech 7100 Preconcentrator for use as the sample concentration and introduction system, and an Entech 3100 Canister Cleaning System for cleaning and evacuation of canisters after analysis.

In 2014, there were two incidents at the underground WIPP site, which affected the sampling of VOCs. The first incident was an underground fire on February 5th, 2014, and the second was an underground radiological release on February 14th, 2014. The last regular samples were collected from the WIPP underground on February 3rd, 2014. As a result of these two incidents; the WIPP began collection of surface samples on February 26th, 2014 to ensure that VOCs on the surface were well within regulatory limits and to confirm that VOCs, Hydrogen, and Methane were not seeping from the underground disposal panels.

VOC Project Expansion

Originally, the VOC laboratory was set up in room 149 in the science laboratory wing at the CEMRC facility and only included the equipment necessary for Confirmatory VOCs analysis. In late 2003, the Department of Energy (DOE) requested that the CEMRC expand its capabilities to prepare for the analysis of headspace gas (HSG) samples collected from waste drums required under the WIPP Permit, Attachment B. In preparation for this expansion of scope, the CEMRC purchased a HSG analysis system consisting of a 6890/5973N Agilent GC/MS with a loop injection system and three Entech 7032 auto-samplers installed in series. Also included in this purchase was an Entech 3100A oven-based canister cleaning system, an Entech 4600 Dynamic Diluter for automatic preparation of VOCs calibration standards, and fifty 400 mL Silonite-coated mini-canisters with Nupro valves and attached pressure gauges.

After a few months of VOCs Confirmatory Analyses, it became critical to expand the laboratory to accommodate the addition of a backup analysis system. This shortcoming was noted by auditors for the next two years. While the CEMRC did purchase a backup Preconcentrator to minimize system downtime, there was no available space in which to set up the backup GC/MS instrument.

With the addition of headspace gas analysis, it was decided in July 2005 to move the VOCs Confirmatory Analysis and Headspace Gas Analysis programs from the Environmental Chemistry (EC) group into the newly created Organic Chemistry (OC) Group. The primary management focus for the EC group was research oriented, whereas the functions of the OC group were regulatory in nature and required different QA/QC measures and documentation.
Analyses were originally conducted by manually changing the sample attached to the preconcentrator for each sample. Due to the need to maximize efficiency, an Entech 7016 canister autosampler was obtained in June 2005. This autosampler allows for up to sixteen samples to be run in sequence with minimal operator supervision.

Funding was obtained in mid-2005 through a DOE baseline change request to remodel the former CEMRC garage into a functional GC/MS Laboratory. The design for the remodel was completed in late 2005, and construction began in January 2006. Construction was completed in April 2006 and the OC Group moved into the newly-created laboratory space.
Also at this time, a backup Agilent 6890/5973 GC/MS system was transferred to the CEMRC by the Central Characterization Project (CCP) for use in headspace gas analysis and a backup autosampler for HSG analysis was purchased by the CEMRC. Shortly thereafter a new Agilent 6890/5975 GC/MS was obtained with a portion of the lab setup funding to be used as a backup analysis system for the Confirmatory VOCs Monitoring.

Although the CEMRC performed well on the DOE audit for the headspace gas analysis project, a decision was made not to submit these samples for analysis at CEMRC. Instead, some of

the equipment obtained for this project is currently being used for analysis of closed room samples for VOCs and percent levels of hydrogen and methane.

In 2015, CEMRC purchase a new Agilent 7820/5977 GC/MS along with an Entech 7200/7016D preconcentrator/autosampler system for analysis of low-levels of VOCs at the part-per-trillion volume (pptv) level.

The VOC Monitoring expanded from 353 samples in 2005 to 430 samples in 2006. Analysis of closed room samples for VOCs, hydrogen, and methane began in 2007 as well and continues to the present. In 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, and 2015 CEMRC analyzed a total of 749, 608, 571, 711, 615, 559, 709, 342, and 253 samples for VOCs and 182, 254, 339, 441, 398, 376, 360, and 46 samples, respectively, for hydrogen and methane. Hydrogen and methane samples were not collected for analysis in 2015 and 2016 as a result of the underground fire and radiological release events that occurred in 2014. In 2016, the CEMRC analyzed a total of 233 samples for VOCs collected from WIPP above ground locations.

Underground sampling was restarted in December 2016 and the CEMRC received these samples in January 2017. Since the CEMRC VOC lab is considered a clean lab (i.e. free of radiological contamination), the underground samples which are collected in radiologically contaminated areas need to be free released by the WIPP facility prior to being delivered to the CEMRC. NWP personnel use filters in the flow path of the sample collection apparatus to reduce the potential amount of radioactive particles that could enter the sample canisters. Additionally, the filters are sent for isotopic analysis to ensure that the results are below MDL, and canisters are analyzed for any external or other dose contributors. The canisters are only delivered to CEMRC when it is determined that they meet the previously established free release limits. Due to the extra precautions and radiological analysis tests performed prior to delivery, the canisters are generally delivered to the CEMRC two to three weeks after sample collection has occurred. This reduces the amount of time allowed to perform sample analysis as the CEMRC has only thirty days from the date of sample collection to complete the analysis process otherwise VOC constituents will begin to degrade within the canister.

Methods for Volatile Organic Compound Monitoring

Confirmatory VOCs Monitoring requires method detection limits at low parts per billion volume (ppbv) range. This type of analysis requires pre-concentration of a given volume of ambient air into a much smaller volume prior to introduction into the GC column. In order to maintain performance of the mass analyzer, most of the water vapor and carbon dioxide present in the air sample must be removed prior to analysis. The Entech 7100 Preconcentrator performs these tasks automatically by transferring the sample through three consecutive cryogenic traps at different controlled temperatures. This results in very low detection limits unattainable without cryogenic preconcentration.

Stock cylinders of Calibration Standard and Laboratory Control Sample gases are purchased certified from a reputable supplier, and then diluted to working concentrations with Ultra-High Purity (UHP) Nitrogen using the Entech 4600 Dynamic Diluter. Canisters are cleaned after sample analysis using the Entech 3100 Canister Cleaning system, which consists of a computerized control module with vacuum pumps and an oven containing a passivated manifold with fittings for connection of canisters. The control software initiates the cleaning of canisters by heating coupled with multiple pressurization/evacuation cycles. A blank sample is analyzed from each cleaning batch as a control to assure proper cleaning has been achieved.

Analyses for Volatile Organic Compound Monitoring were conducted under procedures using concepts of EPA Method TO-15 *"Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS)"* (1999).

Quality assurance requirements for these activities were detailed in the *"Quality Assurance Project Plan for Volatile Organic Compound Monitoring (WP 12-VC.02)"* prepared by the NWP. CEMRC personnel wrote procedures for this project under the CEMRC Quality Assurance Plan, which were verified, validated, and placed in the CEMRC Document Control Program. Procedures were composed to include QA requirements from EPA Method TO-15 and all WIPP documents relevant to the Confirmatory Monitoring Program. See Table 8-1 for a list of CEMRC Procedures for Confirmatory Monitoring.

In November 2006, a WIPP permit modification incorporated an expansion of sampling in the Volatile Organic Compounds Monitoring Program. Originally, the samples were collected from only two stations in the WIPP underground (VOC-A and VOC-B). The permit change required sampling from closed rooms within the current panel until the entire panel is full. Therefore, Attachment N now refers to both Repository VOCs Monitoring and Disposal Room Monitoring.
Table 8-2 summarizes the ten permit specified target compounds and their required reporting limits for different types of samples. Trichloroethylene was an additionally requested compound at the beginning of 2014, but was made a target analyte based on an order from NMED in May 2014.

Method Modification for Analysis of Low-Levels of VOCs

The February 2014 underground radiological incident essentially made it impossible to collect samples in the WIPP underground due to the presence of radiological contamination. As a result, it was decided to begin collection of surface samples to ensure worker safety by monitoring the level of VOC seepage from the underground.

Based on this change, the CEMRC modified the regular VOC analysis method to analyze low-levels of VOCs. The regular method was based on a calibration range of 1 to 100 ppbv; the

calibration range of the modified method is 0.2 to 10 ppbv. This ensured that sub-ppbv level VOCs can be accurately reported as the method reporting limit for undiluted samples was changed to 0.2 ppbv. The regular and modified methods are based on the GC/MS full scan mode, wherein, the system will monitor a range of masses to detect compound fragments within that range. This full scan mode is quite useful to monitor unknown compounds in a sample, but the major drawback, is that it prevents the GC/MS system from being calibrated to a much lower range.

The CEMRC was tasked with developing methodology for analysis of target analytes in the pptv range using the Selected Ion Monitoring (SIM) GC/MS mode. SIM is a GC/MS scanning mode in which only a limited mass-to-charge ratio range is transmitted/detected by the instrument, as opposed to the full spectrum range. The SIM mode increases sensitivity for target analytes through the selective detection of ions most indicative of the compounds of interest. Additionally, the CEMRC has developed a low-level VOC analysis method using the SIM mode where the low calibration level is 50 pptv (0.05 ppbv) with MDLs less than 10 pptv. As a result, the SIM mode is 10 to 100 times more sensitive than the full scan mode. The CEMRC has been analyzing surface samples using both the SIM and full scan modes synchronously since December 2014.

Methods for Hydrogen And Methane Analysis

The analysis of hydrogen and methane in closed room samples began in August 2007. Under the analysis scheme used at the CEMRC, sample canisters would be pressurized to twice the canister pressure (if not already received at above atmospheric pressure) by the addition of ultra-high purity nitrogen, and then simultaneously analyzed for hydrogen and methane by a GC/Thermal Conductivity Detector (TCD) and screened for VOCs by GCMS. The sampling system incorporates three auto-samplers in series to allow for the analysis of two complete batches of six 6L samples per run. Samples from the auto-samplers pass through heated transfer lines into two injection loops attached to an automated valve for simultaneous injection into the GC. The VOC screening results are used to determine pre-analysis dilutions required for analysis by Method TO-15. The hydrogen and methane analysis results are reported in separate data packages from the VOCs results. Quality assurance requirements for these activities were detailed in the *"Quality Assurance Project Plan for Hydrogen and Methane Monitoring (WP 12-VC.04)"* prepared by the NWP.

Laboratory Precision

Laboratory Control Sample (LCS) and LCS-duplicate are analyzed at a rate of once per batch, or once each ten samples, whichever is applicable, to verify instrument calibration and quantitative analytical accuracy. LCS is a standard that contains compounds of interest which have been prepared from a different source than that used to prepare the calibration standard.

An LCS is the same as a spiked blank or blank spike. The LCS % recovery must be within ± 40% for all target and additional requested compounds. The relative percentage deviation (RPD) must be 25% or less for all target and additional requested compounds. The laboratory achieved the precision limit for all the target compounds. Figures 8-1 through 8-4 show an example of laboratory precision through LCS % recovery and RPD for the target analytes Carbon tetrachloride and Trichloroethylene using the low-level method in SIM mode.

Results and Discussion

The OC lab analyzed a total of 233 surface samples in 2016 using GC/MS SIM/scan methods. All of the samples were analyzed and reported in a timely manner under an extensive quality assurance (QA) / quality control (QC) program. All of these samples achieved 100% completeness.

The OC lab also received a number of canisters for cleaning and certification at various times throughout the year. All of the canisters were cleaned and certified with appropriate QA/QC in place. The requirements for analysis of low-levels of VOCs made it necessary to clean and certify each and every canister and Passive Air Sampling Kit (PASK) to ensure that the VOC levels were well below the MRL. In 2016, CEMRC cleaned 271 canisters and 268 PASKs, and all of these were individually certified using low-level GC/MS SIM/scan method.

Batch reports for VOCs results are submitted in hardcopy in the EPA Contract Laboratory Program format. An electronic report in the client's specified format is also provided for each batch. Hardcopy and electronic reports for hydrogen and methane analyses are submitted in the formats specified by the client. Copies of batch reports and all QA records associated with these analyses are maintained according to the CEMRC records management policies, detailed in the QAP.

No Hydrogen/Methane samples were analyzed in 2016.

Laboratory Proficiency Testing Plan

In January 2016, the New Mexico Environment Department (NMED) approved a Permit modification that incorporated the use of ambient air sampling for VOCs at WIPP. The April 2016, Class 1 Permit modification revised Permit, Part 4.6.2.1 and Attachment N, Section N-5e adding an option for proficiency testing (PT). The Permit now requires that the NWP develop and implement a Laboratory Performance Evaluation Plan or participate in PT for the Repository Volatile Organic Compound Monitoring Program. On May 2, 2016, the Permittees notified NMED of the intention to require CEMRC to participate in PT. This plan addresses the requirements in Permit Attachment N, Section N-5e for PT.

The NWP/CEMRC identified low level PT provided by Battelle Inc. which is contracted directly to the EPA. This PT program is part of the National Air Toxics Trends Station (NATTS) Program which monitors low level VOCs in ambient air across the United States. The CEMRC is responsible for initiating and maintaining participation in the PT program. In accordance with the new requirement, the CEMRC participated in the NATTS program in June 2016. Although only six of the ten WIPP target compounds were present in the PT canister, all PT results submitted by the CEMRC were within the acceptable criteria set forth by the PT provider.

Summary Statements

Due to the proprietary nature of the VOC data, none are reported herein. The success of the VOC Monitoring Program and the successful HSG Program audit demonstrate CEMRC's ability to initiate new programs to successfully perform regulatory monitoring tasks in accordance with specific QA/QC requirements.

The CEMRC successfully participated in proficiency testing as set forth by the NMED and the NWP. The CEMRC also underwent an extensive external audit in August 2016. As there were no findings during the audit, it showed that CEMRC has performed in accordance with contractual, regulatory, programmatic, and procedural requirements.

The CEMRC presently has the capability to analyze over 2,000 VOC and hydrogen/ methane samples per year. Additionally, the CEMRC has the instrumentation and facilities capable of analyzing air samples for VOCs from and around Carlsbad which might be affected due to the ever increasing mining, oil and gas industries; however, this segment of the market has yet to be served by the CEMRC as of the date of this report.

Table 8-1: CEMRC Procedures for Volatile Organic Compounds and Hydrogen/Methane Monitoring Program

Procedure Number	Procedure Title
OC-PLAN-001	Quality Assurance Project Plan for Analysis of Volatile Organic Compounds and/or Hydrogen and Methane in Canister Samples
OC-PROC-002	Preparation of Canisters and Sample Trains for Ambient Air Sampling
OC-PROC-003	Gas Chromatography-Mass Spectrometry Analysis of Volatile Organic Compounds (VOCs) in Ambient Air from Canisters at
OC-PROC-004	Preparation of Calibration Standards in Specially Prepared Canisters for Analysis by Gas Chromatography/Mass Spectrometry
OC-PROC-005	Data Validation and Reporting of Volatile Organic Compounds from Gas Chromatography/Mass Spectrometry Analysis of Ambient Air in Canisters for the WIPP Volatile Organic Compound Monitoring Plan
OC-PROC-006	Receipt, Control, and Storage of Gas Samples in Passivated Canisters
OC-PROC-009	Analysis of Hydrogen and Methane in Passivated Canisters Using Gas Chromatography with Thermal Conductivity Detection

Table 8-2: Compounds of Interest for WIPP Confirmatory Volatile Organic Compounds Monitoring Program

Compound	Required Repository Surface Monitoring MRL for SIM mode (ppbv)	Required Repository Surface Monitoring MRL for SCAN mode (ppbv)	Required Disposal Room MRL (ppbv)
1,1-Dichloroethylene	0.1	0.2	500
Carbon tetrachloride	0.1	0.2	500
Methylene chloride	0.1	0.2	500
Chloroform	0.1	0.2	500
1,1,2,2-Tetrachloroethane	0.1	0.2	500
1,1,1-Trichloroethane	0.1	0.2	500
Chlorobenzene	0.1	0.2	500
1,2-Dichloroethane	0.1	0.2	500
Toluene	0.1	0.2	500
Trichloroethylene	0.1	0.2	500

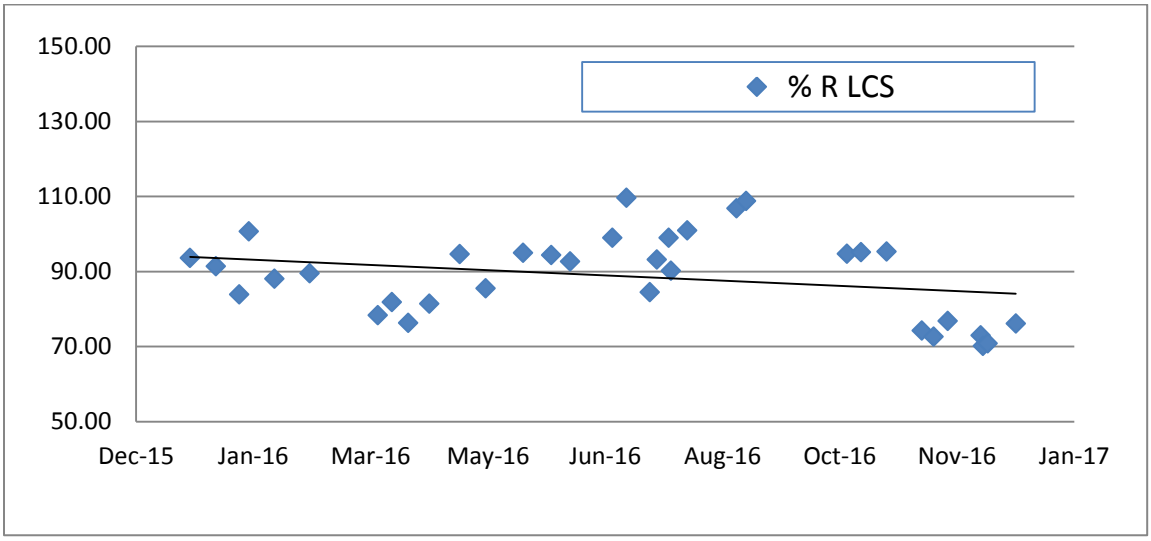


Figure 8-1: Percent Recovery of Carbon Tetrachloride in LCS (Recovery range: 60-140%) using low-level GC/MS SIM mode

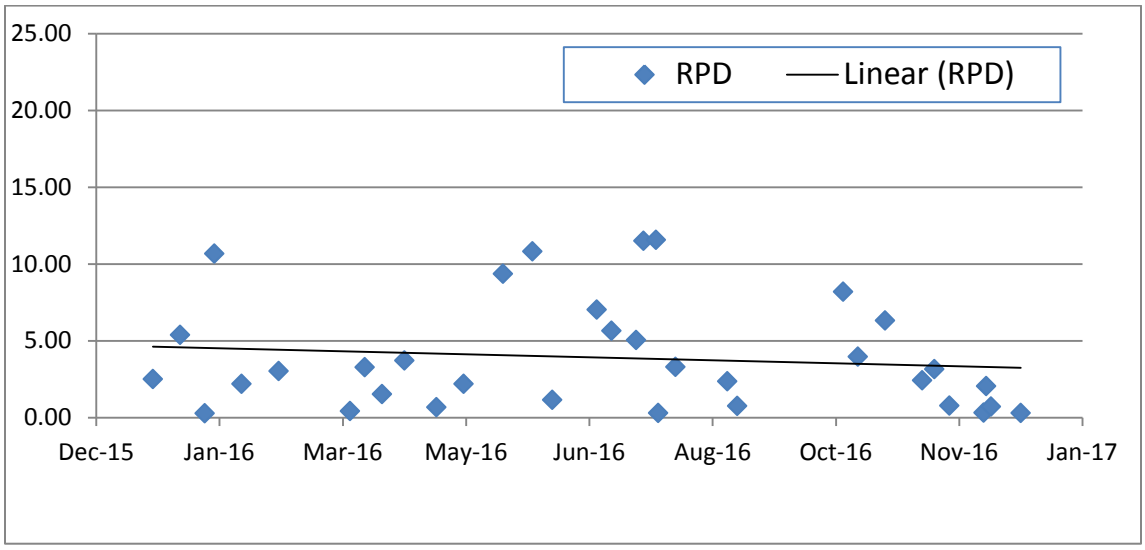


Figure 8-2: Relative Percent Deviation (RPD) between LCS and LCS-Duplicate for Carbon Tetrachloride (RPD range: 25%) using low-level GC/MS SIM mode

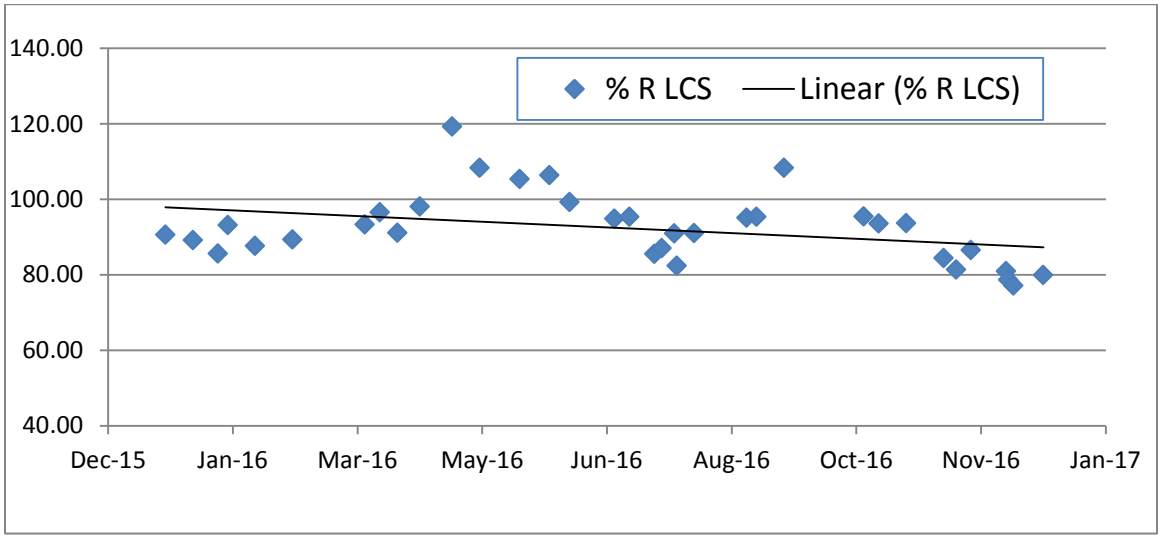


Figure 8-3: Percent Recovery of Trichloroethylene in LCS (Recovery range: 60-140%) using low-level GC/MS SIM mode

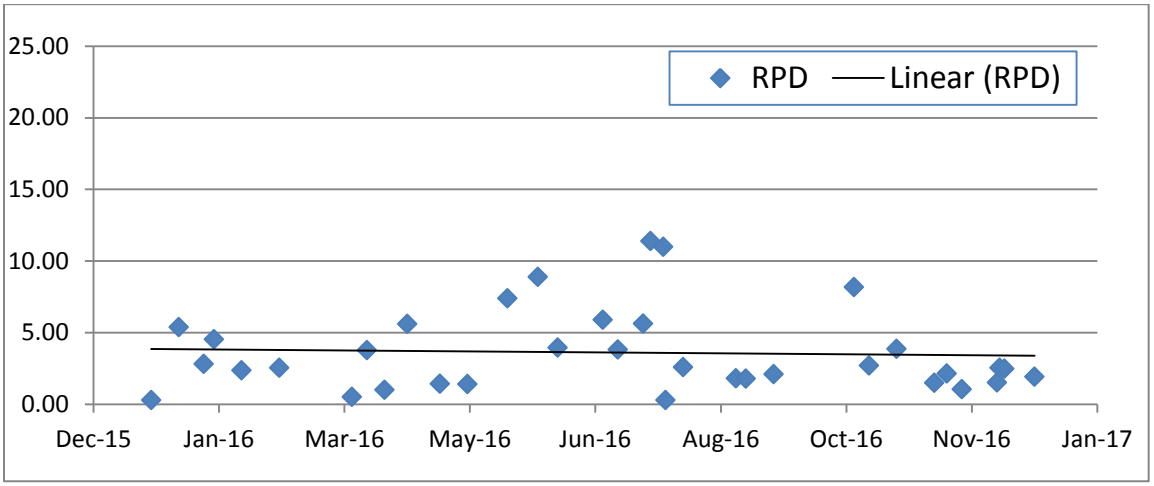


Figure 8-4: Relative Percent Deviation (RPD) between LCS and LCS-Duplicate for Trichloroethylene (RPD range: 25%) using low-level GC/MS SIM mode

CHAPTER 9

Quality Assurance

General Analytical Quality Assurance

Quality assurance and quality control practices encompass all aspects of CEMRC's WIPP Environmental Monitoring Programs (WIPP-EM). The development and implementation of an independent health and environmental monitoring program has been CEMRC's primary activity. The multilayered components of the CEMRC Quality Assurance (QA) Program ensure that all analytical data reported in this report are reliable and of high quality, and that all environmental monitoring data meet quality assurance and quality control objectives.

The CEMRC is subject to the policies, procedures and guidelines adopted by NMSU, as well as state and federal laws and regulations that govern the operation of the University and radiological facilities. Since its inception, CEMRC's WIPP-EM program has been conducted as a scientific investigation, meaning that it operates without any compliance, regulatory, or oversight responsibilities. As such, there are no specific requirements for reporting data other than following good scientific practices.

Samples for the CEMRC's WIPP-EM Programs were collected by personnel trained in accordance with approved procedures. Established sampling locations were accurately identified and documented to ensure continuity of data. Field duplicate samples were used to assess sampling and measurement precision. Quality control in the analytical laboratories is maintained through tracking and verification of analytical instrument performance, through the use of American Chemical Society certified reagents, through the use of National Institute of Standards and Technology (NIST) traceable radionuclide solutions and through verification testing of radionuclide concentrations for tracers not purchased directly from NIST or Eckert and Ziegler Analytics. When making laboratory solutions, volumes and lot numbers of stock chemicals are recorded. Prior to weighing radionuclide tracers and samples, the balance being used is checked using NIST traceable weights.

Control checks were performed on all nuclear counting instrumentation each day or prior to counting a new sample. The type of instrument and methods used for performance checks were as follows: for the Protean 9604 gas-flow α/β proportional counter used for the FAS program, efficiency control charting was performed using ^{239}Pu and ^{90}Sr check sources along with ensuring that α/β cross-talk was within limits. Sixty-minute background counts were recorded daily. Two blanks per week for the FAS program were counted for 20 hours and were used as a background history for calculating results.

Routine background determinations were made on the HPGe detector systems by counting blank samples, and the data was used to blank correct the sample concentrations.

For the alpha spectrometer, efficiency, resolution and centroid control charting was performed using Eckert and Ziegler Analytics check sources on a regular basis. Before each sample count, pulser checks were performed to ensure acceptable detector resolution and centroid. Blanks counted for 5 days were used as a background history for calculating results. Analytical data were verified and validated as required by project-specific quality objectives before being used to support decision making.

CEMRC also participates in the two national performance evaluation programs, NIST Radiochemistry Inter-comparison Program (NIST-RIP) (Figure 9-5) and the DOE-Mixed-Analyte Performance Evaluation Program (MAPEP) (Figure 9-6) for soil, air filter and water analysis. The proficiency tests help to ensure the accuracy of analytical results reported to DOE and other stakeholders, while also providing an efficient means for laboratories to demonstrate analytical proficiency. Under these programs, CEMRC analyzed blind check samples, and the analysis results were compared with the official results measured by the MAPEP, and NRIP laboratories. During 2016, CEMRC radio-analytical program analyzed MAPEP- air filter, water, soil, gross alpha/beta on air filters & water and unknown sample matrix and NIST-NRIP - glass fiber filters, soil and acidified water samples. Isotopes of interest in these performance evolution programs were $^{233/234}$U, ^{238}U, ^{238}Pu, $^{239+240}$Pu, and ^{241}Am, ^{244}Cm and gamma emitters. The analyses were carried out using CEMRC's actinide separation procedures, and were treated as a regular sample set to test regular performance. CEMRC's results were consistently close to the known value. MAPEP and NIST-NRIP results are presented in this annual report. All analysis results except for ^{134}Cs for MAPEP soil and ^{234}U for NIST soil and air filter were deemed unacceptable. Based on the number of A (Acceptable) ratings earned by CEMRC for the analysis of performance evaluation samples, the laboratory provided accurate and reliable radionuclide analysis data for the WIPP environmental samples. In addition, for each set of samples, reagent blank and tracer spikes are also carried through the entire separation and counting process for recovery determination and quality control.

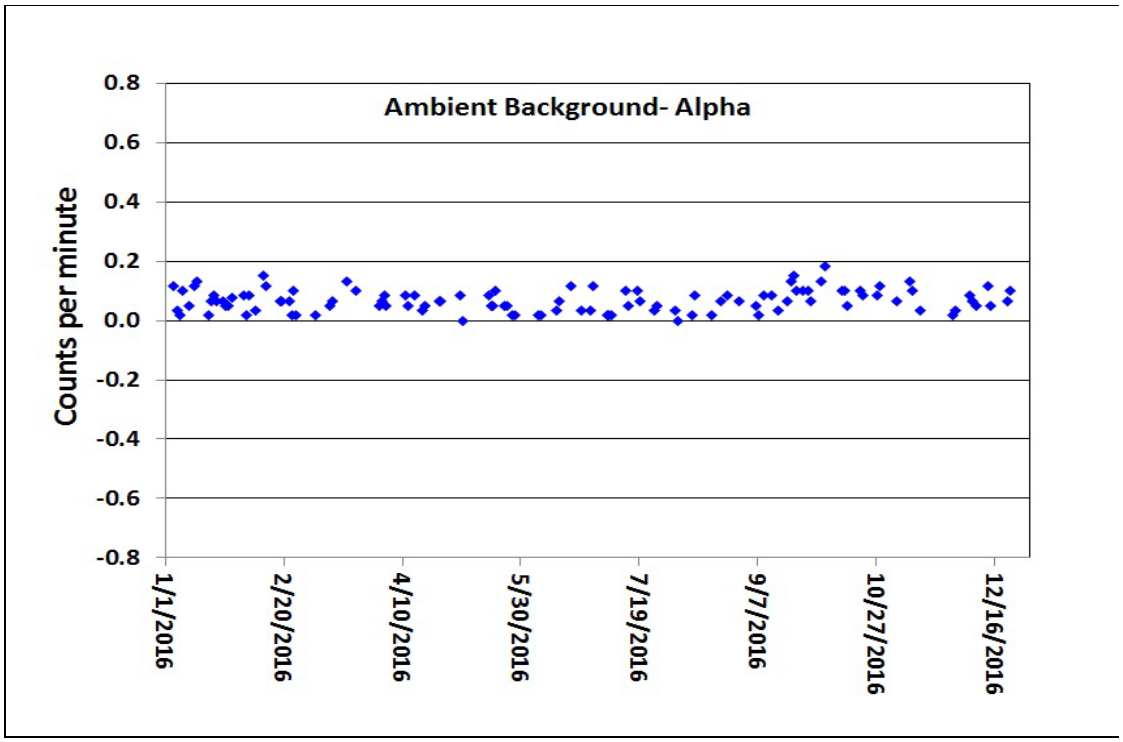


Figure 9-1: Sixty Minutes Alpha Ambient Background Count for the PIC-MPC 9604 Gross Alpha and Beta

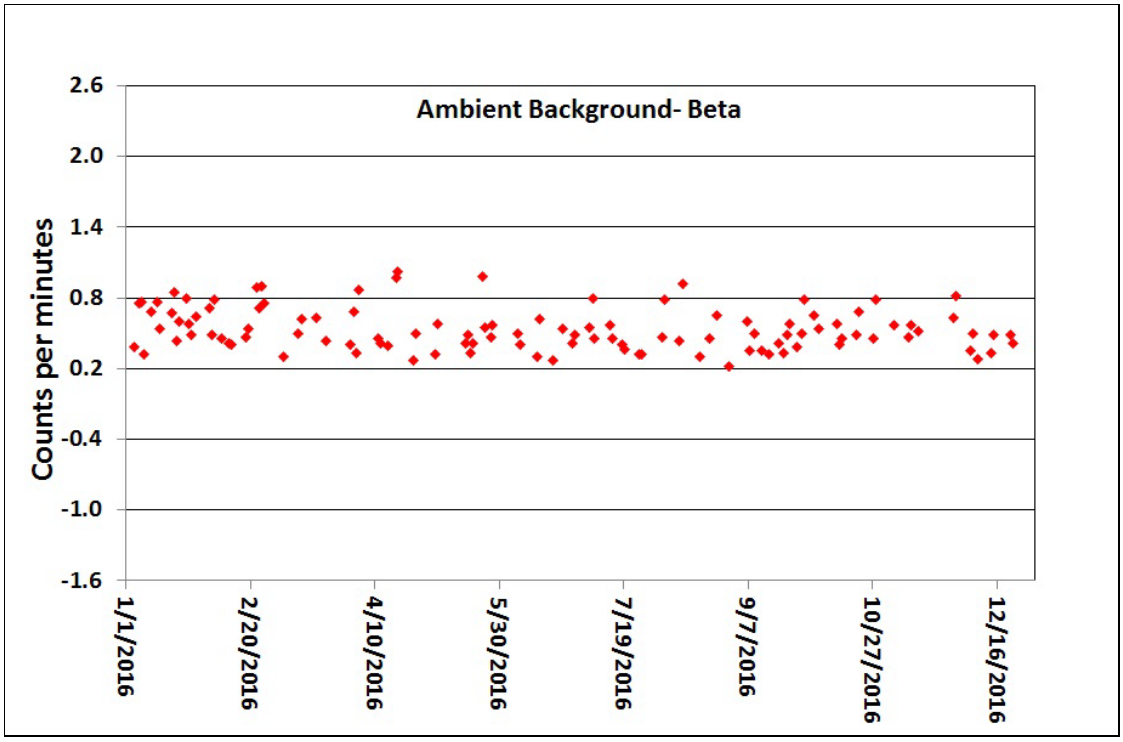


Figure 9-2: Sixty Minutes Beta Ambient Background Count for PICMPC 9604 Gross Alpha and Beta Counter

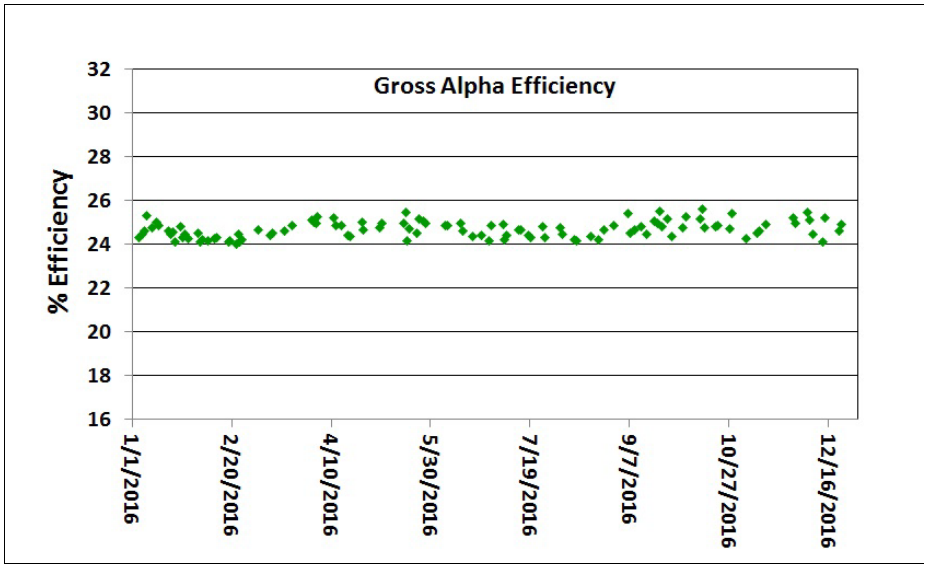


Figure 9-3: Control Chart of Daily Alpha Efficiency of the PICMPC 9604 Gross Alpha and Beta Counter

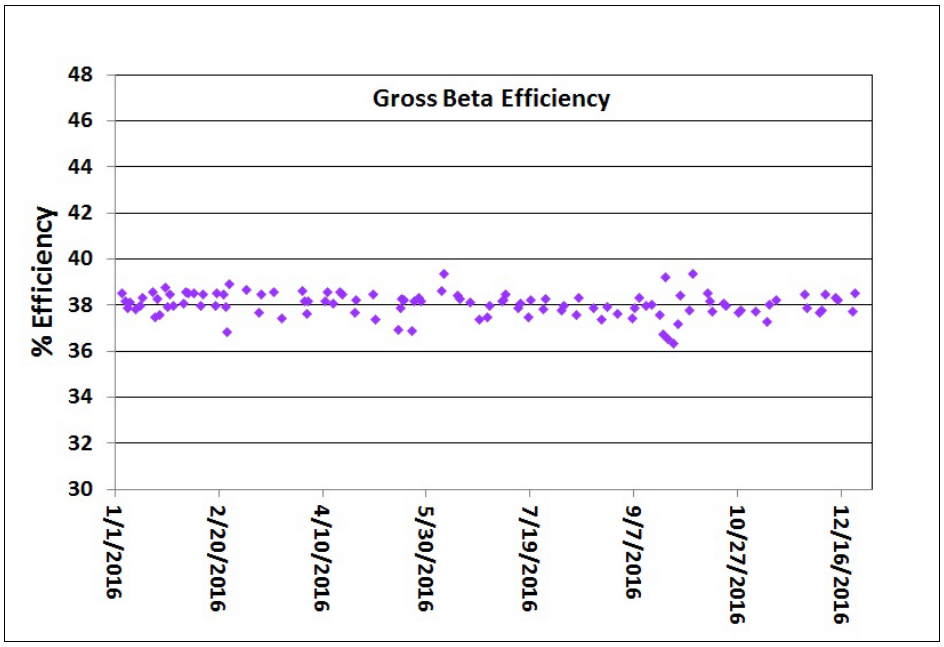


Figure 9-4: Control Chart of Daily Beta Efficiency of the PIC-MPC 9604 Gross Alpha and Beta Counter

U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, MD

REPORT OF TRACEABILITY

Carlsbad Environmental Monitoring and Research Center
Carlsbad, NM

Test Identification	NRIP'16-AF
Matrix Description	^{60}Co, ^{90}Sr, ^{137}Cs, ^{230}Th, ^{234}U, ^{235}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, and ^{241}Am on Glass-Fiber Filters[1]
Test Activity Range	0.02 Bq•sample^{-1} to 250 Bq•sample^{-1}
Reference Time	12:00 EST, April 1, 2016

Measurement Results

Nuclide	NIST Value [2,3]		Reported Value[4]		Difference[5]
	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, k=2)	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, k=2)	(±% Bias)
^{60}Co	336.2	0.62	315.1	7.2	-6.3
^{137}Cs	793.7	0.79	767.2	6.7	-3.3
^{234}U	3.52	1.00	4.69	13.1	33.2
^{235}U	0.168	0.65	0.199	23.9	18.3
^{238}U	3.65	0.63	3.65	13.3	0.0
^{238}Pu	2.71	0.71	2.78	12.9	2.5
^{239}Pu	2.31	0.71	2.34	13.1	1.6
^{241}Am	2.59	0.33	2.57	13.9	-0.8

Methods

	NIST[6]	Reporting Laboratory[7]
Activity Measurements	Alpha- and Beta-Spectrometry Mass Spectrometry	Alpha and Gamma Spectrometry

Evaluation (per ANSI N42.22)

Nuclide	ANSI N42.22 Traceable[8]	Traceability Limit (%)
^{60}Co	Yes	10.2
^{137}Cs	Yes	9.7
^{234}U	No	26.3
^{235}U	Yes	42.3

Nuclide	ANSI N42.22 Traceable[8]	Traceability Limit (%)
^{238}U	Yes	19.9
^{238}Pu	Yes	19.9
^{239}Pu	Yes	20.0
^{241}Am	Yes	20.6

Samples Distributed 29 July 2016
Reporting Data Received 26 September 2016

For the Director

Michael P. Unterweger, Group Leader
Radioactivity Group
Physical Measurement Laboratory
(continued)

Figure 9-5: Participation in 2016-NIST Radiochemistry Intercomparison Program

U.S. DEPARTMENT OF COMMERCE

National Institute of Standards and Technology
Gaithersburg, MD

REPORT OF TRACEABILITY

**Carlsbad Environmental Monitoring and Research Center,
Carlsbad, NM**

Test Identification	NRIP'16-AW
Matrix Description	^{60}Co, ^{90}Sr, ^{137}Cs, ^{230}Th, ^{234}U, ^{235}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, and ^{241}Am in acidified water[1]
Test Activity Range	0.01 Bq•sample^{-1} to 50 Bq•sample^{-1}
Reference Time	12:00 EST, April 1, 2016

Measurement Results

Nuclide	NIST Value [2,3]		Reported Value[4]		Difference[5]
	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, k=2)	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, k=2)	(%)
^{60}Co	336.2	0.62	352.1	6.8	4.7
^{137}Cs	793.7	0.79	793.6	5.4	0.0
^{234}U	3.52	1.00	4.26	14.8	21
^{235}U	0.168	0.65	0.168	47.9	0.2
^{238}U	3.65	0.63	3.70	15.1	1.2
^{238}Pu	2.71	0.71	2.65	15.0	-2.4
^{239}Pu	2.31	0.71	2.32	15.4	0.7
^{241}Am	2.59	0.33	2.44	15.6	-6.1

Methods

	NIST[6]	Reporting Laboratory[7]
Activity Measurements	Alpha-, Beta-, Gamma-Spectrometry Mass Spectrometry	Alpha-, Gamma-Spectrometry

Evaluation (per ANSI N42.22)

Nuclide	ANSI N42.22 Traceable[8]	Traceability Limit (%)
^{60}Co	Yes	10.8
^{137}Cs	Yes	8.2
^{234}U	Yes	27
^{235}U	Yes	72

Nuclide	ANSI N42.22 Traceable[8]	Traceability Limit (%)
^{238}U	Yes	23
^{238}Pu	Yes	22
^{239}Pu	Yes	23
^{241}Am	Yes	22

Samples Distributed 8 August 2016
Reporting Data Received 26 September 2016

For the Director

Michael P. Unterweger, Group Leader
Radioactivity Group
Physical Measurement Laboratory
(continued)

Figure 9-5: Participation in 2016-NIST Radiochemistry Intercomparison Program (continued)

U.S. DEPARTMENT OF COMMERCE

National Institute of Standards and Technology
Gaithersburg, MD

REPORT OF TRACEABILITY

**Carlsbad Environmental Monitoring and Research Center,
Carlsbad, NM**

Test Identification NRIP'16-SS
Test Radionuclides ^{60}Co, ^{90}Sr, ^{137}Cs, ^{230}Th, ^{234}U, ^{235}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, and ^{241}Am in soil[1]
Test Activity Range 0.01 Bq•sample^{-1} to 250 Bq•sample^{-1}
Reference Time 12:00 EST, April 1, 2016

Measurement Results

Nuclide	NIST Value [2,3]		Reported Value[4]		Difference[5]
	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, k=2)	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, k=2)	(%)
^{60}Co	336.2	0.62	318.7	7.4	-5.2
^{137}Cs	793.7	0.79	787.3	7.3	-0.8
^{234}U	3.52	1.00	5.50	14.1	56.3
^{235}U	0.168	0.65	0.222	25.4	31.9
^{238}U	3.65	0.63	4.20	14.3	15.0
^{238}Pu	2.71	0.71	2.71	13.3	-0.2
^{239}Pu	2.31	0.71	2.25	13.4	-2.4
^{241}Am	2.59	0.33	2.41	12.8	-7.0

Methods

	NIST[6]	Reporting Laboratory[7]
Activity Measurements	Alpha-, Beta-, Gamma-Spectrometry, Mass Spectrometry	Alpha- and Gamma-Spectrometry

Evaluation (per ANSI N42.22)

Nuclide	ANSI N42.22 Traceable[8]	Traceability Limit (%)
^{60}Co	Yes	10.6
^{137}Cs	Yes	10.9
^{234}U	No	33
^{235}U	Yes	50

Nuclide	ANSI N42.22 Traceable[8]	Traceability Limit (%)
^{238}U	Yes	25
^{238}Pu	Yes	19.9
^{239}Pu	Yes	19.7
^{241}Am	Yes	17.8

Samples Distributed 25 July 2016
Reporting Data Received 26 September 2016

For the Director

Michael P. Unterweger, Group Leader
Radioactivity Group
Physical Measurement Laboratory
(continued)

Figure 9-5: Participation in 2016-NIST Radiochemistry Intercomparison Program (continued)

MAPEP Mixed Analyte Performance Evaluation Program

Department of Energy RESL - 1955 Fremont Ave, MS4149 - Idaho Falls, ID 83415

Laboratory Results For MAPEP-16-RdF35

(CMRC01) Carlsbad Environmental Monitoring and Research Center
1400 University Dr.
Carlsbad, NM 88220

Inorganic — Units: (ug/sample)

Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Uranium-235	NR	0.0903				0.0632 - 0.1174		
Uranium-238	NR	12.5				8.8 - 16.3		
Uranium-Total	NR	12.6				8.8 - 16.4		

Radiological — Units: (Bq/sample)

Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Americium-241	2.61E-04		A			False Positive Test	2.01E-04	
Cesium-134	2.08E+00	2.04	A		2.0	1.43 - 2.65	8.06E-02	A
Cesium-137	1.88E+00	1.78	A		5.6	1.25 - 2.31	1.16E-01	A
Cobalt-57	2.56E+00	2.48	A		3.2	1.74 - 3.22	1.15E-01	A
Cobalt-60	3.28E+00	3.26	A		0.6	2.28 - 4.24	9.89E-02	A
Manganese-54	2.89E+00	2.75	A		5.1	1.93 - 3.58	1.29E-01	A
Plutonium-238	7.92E-02	0.0693	A		14.3	0.0485 - 0.0901	5.94E-03	A
Plutonium-239/240	5.64E-02	0.0535	A		5.4	0.0375 - 0.0696	4.47E-03	A
Strontium-90	NR	1.03				0.72 - 1.34		
Uranium-234/233	1.57E-01	0.150	A		4.7	0.105 - 0.195	1.13E-02	A
Uranium-238	1.60E-01	0.156	A		2.6	0.109 - 0.203	1.15E-02	A
Zinc-65	7.41E-02		A			False Positive Test	1.05E-01	

Radiological Reference Date: August 1, 2016

Result Flags:

A = Result acceptable Bias <=20%

W = Result acceptable with warning 20% < Bias < 30%

N = Result not acceptable Bias > 30%

RW = Report Warning

NR = Not Reported

Uncertainty Flags:

NOT ACCEPTABLE.....RP<2%

ACCEPTABLE.....2%<=RP<=15%

ACCEPTABLE WITH WARNING.....15%<RP<=30%

Issued 12/1/2016 Printed 12/2/2016

Figure 9-6: Radiochemistry MAPEP 2016 Inter-comparison Results

Radiological — Units: (Bq/sample)

Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
NOT ACCEPTABLE	RP>30%							

Issued 12/1/2016 Printed 12/2/2016

Figure 9-6: Radiochemistry MAPEP 2016 Inter-comparison Results (continued)

MAPEP Mixed Analyte Performance Evaluation Program

Department of Energy RESL - 1955 Fremont Ave, MS4149 - Idaho Falls, ID 83415

Laboratory Results For MAPEP-16-MaS35
(CMRC01) Carlsbad Environmental Monitoring and Research Center
1400 University Dr.
Carlsbad, NM 88220

Inorganic — Units: (mg/kg)

Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Antimony	NR	96.5				67.6 - 125.5		
Arsenic	NR	25.3				17.7 - 32.9		
Barium	NR	155				109 - 202		
Beryllium	NR	4.13				2.89 - 5.37		
Cadmium	NR	4.74				3.32 - 6.16		
Chromium	NR	78.6				55.0 - 102.2		
Cobalt	NR	82.2				57.5 - 106.9		
Copper	NR	123				86 - 160		
Lead	NR	34.4				24.1 - 44.7		
Mercury	NR	0.204				0.143 - 0.265		
Nickel	NR	236				165 - 307		
Selenium	NR	17.7				12.4 - 23.0		
Silver	NR	23.5				16.5 - 30.6		
Technetium-99	NR	8.87E-4				6.21E-4 - 1.15E-3		
Thallium	NR	34.5				24.2 - 44.9		
Uranium-235	NR	0.0695				0.0487 - 0.0904		
Uranium-238	NR	9.7				6.8 - 12.6		
Uranium-Total	NR	9.8				6.9 - 12.7		
Vanadium	NR	65.7				46.0 - 85.4		
Zinc	NR	198				139 - 257		

Radiological — Units: (Bq/kg)

Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Americium-241	6.76E-01		A			False Positive Test	3.70E-01	
Cesium-134	5.31E+00		N	(1)		False Positive Test	1.64	
Cesium-137	1.13E+03	1067	A		5.9	747 - 1387	4.02	A
Cobalt-57	1.28E+03	1190	A		7.6	833 - 1547	3.94	A
Cobalt-60	8.86E+02	851	A		4.1	596 - 1106	1.94	A
Iron-55	NR					False Positive Test		
Manganese-54	6.92E-02		A			False Positive Test	1.76	
Nickel-63	NR	990				693 - 1287		
Plutonium-238	7.01E+01	70.4	A		-0.4	49.3 - 91.5	4.91	A
Plutonium-239/240	5.27E+01	53.8	A		-2.0	37.7 - 69.9	3.77	A
Potassium-40	5.51E+02	588	A		-6.3	412 - 764	5.28	A
Strontium-90	NR	894				626 - 1162		
Technetium-99	NR	556				389 - 723		

Issued 12/1/2016 Printed 12/2/2016

Figure 9-6: Radiochemistry MAPEP 2016 Inter-comparison Results (continued)

Radiological								Units: (Bq/kg)
Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Uranium-234/233	1.30E+02	122	A		6.6	85 - 159	8.98	A
Uranium-238	9.78E+01	121	A		-19.2	85 - 157	6.90	A
Zinc-65	8.07E+02	695	A		16.1	487 - 904	2.36	A

Radiological Reference Date: August 1, 2016

Results Flags:

A = Result acceptable Bias <=20%

W = Result acceptable with warning 20% < Bias < 30%

N = Result not acceptable Bias > 30%

RW = Report Warning

NR = Not Reported

Uncertainty Flags:

NOT ACCEPTABLE.....RP<2%

ACCEPTABLE.....2%<=RP<=15%

ACCEPTABLE WITH WARNING.....15%<RP<=30%

NOT ACCEPTABLE.....RP>30%

RP = Relative Precision

Notes:

(1) = False Positive

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Figure 9-6: Radiochemistry MAPEP 2016 Inter-comparison Results (continued)

MAPEP Mixed Analyte Performance Evaluation Program

Department of Energy RESL - 1955 Fremont Ave, MS4149 - Idaho Falls, ID 83415

Laboratory Results For MAPEP-16-MaW35

(CMRC01) Carlsbad Environmental Monitoring and Research Center
1400 University Dr.
Carlsbad, NM 88220

Inorganic — Units: (mg/L)

Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Antimony	NR	5.26				3.68 - 6.84		
Arsenic	NR	4.08				2.86 - 5.30		
Barium	NR	6.9				4.8 - 9.0		
Beryllium	NR	1.02				0.71 - 1.33		
Cadmium	NR	0.762				0.533 - 0.991		
Chromium	NR	2.35				1.65 - 3.06		
Cobalt	NR	7.73				5.41 - 10.05		
Copper	NR	10.6				7.4 - 13.8		
Lead	NR	3.04				2.13 - 3.95		
Mercury	NR	0.125				0.088 - 0.163		
Nickel	NR	12.5				8.8 - 16.3		
Selenium	NR	0.563				0.394 - 0.732		
Technetium-99	NR	1.85E-5				1.30E-5 - 2.41E-5		
Thallium	NR	1.84				1.29 - 2.39		
Uranium-235	NR	1.12e-3				0.00078 - 0.00146		
Uranium-238	NR	0.154				0.108 - 0.200		
Uranium-Total	NR	0.156				0.109 - 0.203		
Vanadium	NR	2.91				2.04 - 3.78		
Zinc	NR	11.8				8.3 - 15.3		

Radiological — Units: (Bq/L)

Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Americium-241	7.49E-01	0.814	A		-8.0	0.570 - 1.058	4.86E-02	A
Cesium-134	2.24E+01	23.9	A		-6.3	16.7 - 31.1	6.56E-01	A
Cesium-137	8.13E-01		A			False Positive Test	3.69E-01	
Cobalt-57	2.57E+01	27.3	A		-5.9	19.1 - 35.5	8.41E-01	A
Cobalt-60	4.80E-01		A			False Positive Test	3.73E-01	
Hydrogen-3	NR	334				234 - 434		
Iron-55	NR	21.5				15.1 - 28.0		
Manganese-54	1.44E+01	14.8	A		-2.7	10.4 - 19.2	6.41E-01	A
Nickel-63	NR	17.2				12.0 - 22.4		
Plutonium-238	1.03E+00	1.13	A		-8.9	0.79 - 1.47	6.81E-02	A
Plutonium-239/240	1.50E-02	0.013	A			Sensitivity Evaluation	2.78E-03	
Potassium-40	2.54E+02	252	A		0.8	176 - 328	9.96	A
Radium-226	NR	1.33				0.93 - 1.73		
Strontium-90	NR					False Positive Test		

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Figure 9-6: Radiochemistry MAPEP 2016 Inter-comparison Results (continued)

Radiological								Units: (Bq/L)
Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Technetium-99	NR	11.6				8.1 - 15.1		
Uranium-234/233	1.74E+00	1.86	A		-6.5	1.30 - 2.42	1.16E-01	A
Uranium-238	1.78E+00	1.92	A		-7.3	1.34 - 2.50	1.19E-01	A
Zinc-65	1.88E+01	17.4	A		8.0	12.2 - 22.6	1.14	A

Radiological Reference Date: August 1, 2016

Result Flags:

A = Result acceptable Bias <=20%

W = Result acceptable with warning 20% < Bias < 30%

N = Result not acceptable Bias > 30%

RW = Report Warning

NR = Not Reported

Uncertainty Flags:

NOT ACCEPTABLE.....RP<2%

ACCEPTABLE.....2%<=RP<=15%

ACCEPTABLE WITH WARNING.....15%<RP<=30%

NOT ACCEPTABLE.....RP>30%

RP = Relative Precision

Issued 12/1/2016 Printed 12/2/2016

Figure 9-6: Radiochemistry MAPEP 2016 Inter-comparison Results (continued)

MAPEP Mixed Analyte Performance Evaluation Program

Department of Energy RESL - 1955 Fremont Ave, MS4149 - Idaho Falls, ID 83415

Laboratory Results For MAPEP-15-MaW33

(CMRC01) Carlsbad Environmental Monitoring and Research Center
1400 University Dr.
Carlsbad, NM 88220

Inorganic — Units: (mg/L)

Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Antimony	NR	13.6				9.5 - 17.7		
Arsenic	NR	4.07				2.85 - 5.29		
Barium	NR	8.02				5.61 - 10.43		
Beryllium	NR	2.27				1.59 - 2.95		
Cadmium	NR	0.739				0.517 - 0.961		
Chromium	NR	3.83				2.68 - 4.98		
Cobalt	NR	14.8				10.4 - 19.2		
Copper	NR	4.40				3.08 - 5.72		
Lead	NR	3.98				2.79 - 5.17		
Mercury	NR	0.127				0.089 - 0.165		
Nickel	NR	16.8				11.8 - 21.8		
Selenium	NR	0.537				0.376 - 0.698		
Technetium-99	NR	1.15e-5				8.10E-6 - 1.50E-5		
Thallium	NR	2.32				1.62 - 3.02		
Uranium-235	NR	6.59e-4				4.61E-4 - 8.57E-4		
Uranium-238	NR	0.095				0.067 - 0.124		
Uranium-Total	NR	0.095				0.067 - 0.124		
Vanadium	NR	10.3				7.2 - 13.4		
Zinc	NR	15.8				11.1 - 20.5		

Radiological — Units: (Bq/L)

Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Americium-241	9.69E-01	1.055	A		-8.2	0.739 - 1.372	6.32E-02	A
Cesium-134	2.13E+01	23.1	A		-7.8	16.2 - 30.0	6.88E-01	A
Cesium-137	2.87E-02		A			False Positive Test	4.55E-01	
Cobalt-57	2.07E+01	20.8	A		-0.5	14.6 - 27.0	8.49E-01	A
Cobalt-60	1.58E+01	17.1	A		-7.6	12.0 - 22.2	6.86E-01	A
Hydrogen-3	NR	216				151 - 281		
Iron-55	NR	13.1				9.2 - 17.0		
Manganese-54	1.52E+01	15.6	A		-2.6	10.9 - 20.3	7.48E-01	A
Nickel-63	NR	8.55				5.99 - 11.12		
Plutonium-238	6.59E-01	0.681	A		-3.2	0.477 - 0.885	5.13E-02	A
Plutonium-239/240	8.42E-01	0.900	A		-6.4	0.630 - 1.170	5.53E-02	A
Potassium-40	2.06E+02	214	A		-3.7	150 - 278	1.04	A
Strontium-90	NR	4.80				3.36 - 6.24		
Technetium-99	NR	7.19				5.03 - 9.35		

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Figure 9-6: Radiochemistry MAPEP 2016 Inter-comparison Results (continued)

Radiological								Units: (Bq/L)
Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Uranium-234/233	1.08E+00	1.14	A		-5.3	0.80 - 1.48	8.21E-02	A
Uranium-238	1.10E+00	1.18	A		-6.8	0.83 - 1.53	8.03E-02	A
Zinc-65	1.56E+01	13.9	A		12.2	9.7 - 18.1	1.40	A

Radiological Reference Date: August 1, 2015

Result Flags:

A = Result acceptable Bias <=20%

W = Result acceptable with warning 20% < Bias < 30%

N = Result not acceptable Bias > 30%

RW = Report Warning

NR = Not Reported

Uncertainty Flags:

1) NOT ACCEPTABLE.....RP<2%

2) ACCEPTABLE.....2%<=RP<=15%

3) ACCEPTABLE WITH WARNING.....15%<RP<=30%

4) NOT ACCEPTABLE.....RP>30%

RP = Relative Precision

Figure 9-6: Radiochemistry MAPEP 2016 Inter-comparison Results (continued)

MAPEP Mixed Analyte Performance Evaluation Program

Department of Energy RESL - 1955 Fremont Ave, MS4149 - Idaho Falls, ID 83415

Laboratory Results For MAPEP-15-RdF33

(CMRC01) Carlsbad Environmental Monitoring and Research Center
1400 University Dr.
Carlsbad, NM 88220

Inorganic — Units: (ug/sample)

Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Uranium-235	NR	0.086				0.060 - 0.112		
Uranium-238	NR	11.9				8.3 - 15.5		
Uranium-Total	NR	12.0				8.4 - 15.6		

Radiological — Units: (Bq/sample)

Analyte	Result	Ref Value	Flag	Notes	Bias (%)	Acceptance Range	Unc Value	Unc Flag
Americium-241	1.33E-01	0.147	A		-9.5	0.103 - 0.191	8.55E-03	A
Cesium-134	2.37E+00	2.45	A		-3.3	1.72 - 3.19	5.91E-02	A
Cesium-137	1.96E+00	1.96	A		0.0	1.37 - 2.55	6.25E-02	A
Cobalt-57	2.78E+00	2.74	A		1.5	1.92 - 3.56	9.74E-02	A
Cobalt-60	1.69E+00	1.71	A		-1.2	1.20 - 2.22	4.74E-02	A
Manganese-54	2.10E+00	2.11	A		-0.5	1.48 - 2.74	6.55E-02	A
Plutonium-238	1.03E-01	0.104	A		-1.0	0.073 - 0.135	6.84E-03	A
Plutonium-239/240	2.31E-03	0.0025	A			Sensitivity Evaluation	4.14E-04	
Strontium-90	NR	2.18				1.53 - 2.83		
Uranium-234/233	1.36E-01	0.143	A		-4.9	0.100 - 0.186	1.01E-02	A
Uranium-238	1.36E-01	0.148	A		-8.1	0.104 - 0.192	1.01E-02	A
Zinc-65	1.38E+00	1.32	A		4.5	0.92 - 1.72	1.04E-01	A

Radiological Reference Date: August 1, 2015

Result Flags:

A = Result acceptable Bias <=20%

W = Result acceptable with warning 20% < Bias < 30%

N = Result not acceptable Bias > 30%

RW = Report Warning

NR = Not Reported

Uncertainty Flags:

1) NOT ACCEPTABLE.....RP<2%

2) ACCEPTABLE.....2%<=RP<=15%

3) ACCEPTABLE WITH WARNING.....15%<RP<=30%

Issued 12/2/2015 Printed 11/20/2016

Figure 9-6: Radiochemistry MAPEP 2016 Inter-comparison Results (continued)

MAPEP Mixed Analyte Performance Evaluation Program

Department of Energy RESL - 1955 Fremont Ave, MS4149 - Idaho Falls, ID 83415

Laboratory Results For MAPEP-15-XrM33

(CMRC01) Carlsbad Environmental Monitoring and Research Center
1400 University Dr.
Carlsbad, NM 88220

Radiological

Sample ID	Nuclide	Known Activity	Expt'l Activity	Bias (%)
MAPEP-15-XrM33	Am-241	0.077 +/- 0.003 Bq/sample	6.99E-02 +/- 5.11E-03	-9.2
MAPEP-15-XrM33	Cs-134	1.37 +/- 0.04 Bq/sample	1.40E+00 +/- 4.30E-02	2.2
MAPEP-15-XrM33	Cs-137	2.01 +/- 0.05 Bq/sample	2.05E+00 +/- 5.87E-02	2.0
MAPEP-15-XrM33	Co-57	2.43 +/- 0.07 Bq/sample	2.47E+00 +/- 7.68E-02	1.6
MAPEP-15-XrM33	Co-60	1.56 +/- 0.06 Bq/sample	1.54E+00 +/- 3.96E-02	-1.3
MAPEP-15-XrM33	Cm-244	0.105 +/- 0.003 Bq/sample	9.92E-02 +/- 6.85E-03	-5.5
MAPEP-15-XrM33	Ir-192	4.76 +/- 0.15 Bq/sample		
MAPEP-15-XrM33	Mn-54	1.64 +/- 0.05 Bq/sample	1.66E+00 +/- 5.48E-02	1.2
MAPEP-15-XrM33	Pu-238	0.098 +/- 0.003 Bq/sample	9.22E-02 +/- 6.61E-03	-5.9
MAPEP-15-XrM33	Pu-239	0.077 +/- 0.003 Bq/sample	7.61E-02 +/- 5.60E-03	-1.2
MAPEP-15-XrM33	K-40		5.77E-02 +/- 2.49E-01	
MAPEP-15-XrM33	Sr-90	1.19 +/- 0.04 Bq/sample		
MAPEP-15-XrM33	Tc-99	1.11 +/- 0.03 Bq/sample		
MAPEP-15-XrM33	Th-228	0.0155 +/- 0.0014 Bq/sample		
MAPEP-15-XrM33	Th-230	0.0272 +/- 0.0018 Bq/sample		
MAPEP-15-XrM33	Th-232	0.0161 +/- 0.0018 Bq/sample		
MAPEP-15-XrM33	U-234	0.038 +/- 0.002 Bq/sample	3.56E-02 +/- 3.28E-03	-6.3
MAPEP-15-XrM33	U-235		2.77E-03 +/- 7.69E-04	
MAPEP-15-XrM33	U-238	0.117 +/- 0.004 Bq/sample	1.16E-01 +/- 8.55E-03	-0.9
MAPEP-15-XrM33	Zn-65	1.15 +/- 0.04 Bq/sample	1.25E+00 +/- 1.03E-01	8.7

Radiological Reference Date: August 1, 2015

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Figure 9-6: Radiochemistry MAPEP 2016 Inter-comparison Results (continued)

Table 9-1: Examples of the Daily Performance Tests

ICP-MS, Elan DRC-e, for May - June 2016

	Acceptable Ranges		05/27/2016			06/08/2016		
	Criteria for Net Intensity Mean of 5 replicate readings	Required Relative Standard Deviation (%)	Measured Intensity Mean	Relative Standard Deviation	Performance Evaluation	Measured Mean Intensity	Relative Standard Deviation	Performance Evaluation
Be	>1,000	0.0 - 5.0%	6,560.8	1.7	Acceptable	8,525.2	3.4	Acceptable
Mg	>40,000	0.0 - 5.0%	59,467.3	1.3	Acceptable	90,685.6	1.8	Acceptable
In	>250,000	0.0 - 5.0%	390,283.1	1.7	Acceptable	406,477.1	2.5	Acceptable
Pb	>100,000	0.0 - 5.0%	229,567.3	2.4	Acceptable	201,134.4	6.2	Acceptable
Ce	<900,000	0.0 - 5.0%	438,500.6	1.4	Acceptable	442,189.2	2.1	Acceptable
CeO	≤3.0%	N/A	2.6%	N/A	Acceptable	2.9%	N/A	Acceptable
Ba	<900,000	0.0 - 5.0%	349,499.5	1.8	Acceptable	359,067.8	2.1	Acceptable
Ba++	≤3.0%	N/A	1.4%	N/A	Acceptable	2.1%	N/A	Acceptable
Bkgd	≤10.0	N/A	0.4	N/A	Acceptable	0.3	N/A	Acceptable

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WS-235 2009 TNI Evaluation Final Complete Report

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EPA ID: Not Reported
ERA Customer Number: N215603
Report Issued: 03/28/16
Study Dates: 02/08/16 - 03/24/16

TNI Analyte Code	Analyte	Units	Reported Value	Assigned Value	Acceptance Limits	Performance Evaluation	Method Description	Analysis Date	Z Score	Study Mean	Study Standard Deviation	Analyst Name
WS Inorganics (cat# 691, lot# S235-698)												
1505	Alkalinity as CaCO3	mg/L		194	175 - 213	Not Reported				194	4.72	
1575	Chloride	mg/L	97.4	97.4	82.8 - 112	Acceptable	EPA 300.0 2.1 1993	3/10/2016	0.686	95.4	2.89	
1610	Conductivity at 25°C	µmhos/cm		1060	954 - 1170	Not Reported				1070	26.4	
1730	Fluoride	mg/L	3.0	2.99	2.69 - 3.29	Acceptable	EPA 300.0 2.1 1993	3/10/2016	0.578	2.90	0.170	
1820	Nitrate + Nitrite as N	mg/L		8.96	7.62 - 10.3	Not Reported				8.76	0.286	
1810	Nitrate as N	mg/L	8.9	8.96	8.06 - 9.86	Acceptable	EPA 300.0 2.1 1993	3/10/2016	0.481	8.74	0.323	
1125	Potassium	mg/L		31.2	26.5 - 35.9	Not Reported				30.6	1.20	
2000	Sulfate	mg/L	159.0	159	135 - 183	Acceptable	EPA 300.0 2.1 1993	3/10/2016	0.488	156	5.81	
1955	Total Dissolved Solids at 180°C	mg/L		885	708 - 1060	Not Reported				871	25.3	
WS Mercury (cat# 551, lot# S235-666)												
1095	Mercury	µg/L	7.9	8.74	6.12 - 11.4	Acceptable	EPA 200.8 5.4 1994	2/18/2016	-1.72	9.08	0.687	

All analytes are included in ERA's A2LA accreditation. Lab Code: 1539-01
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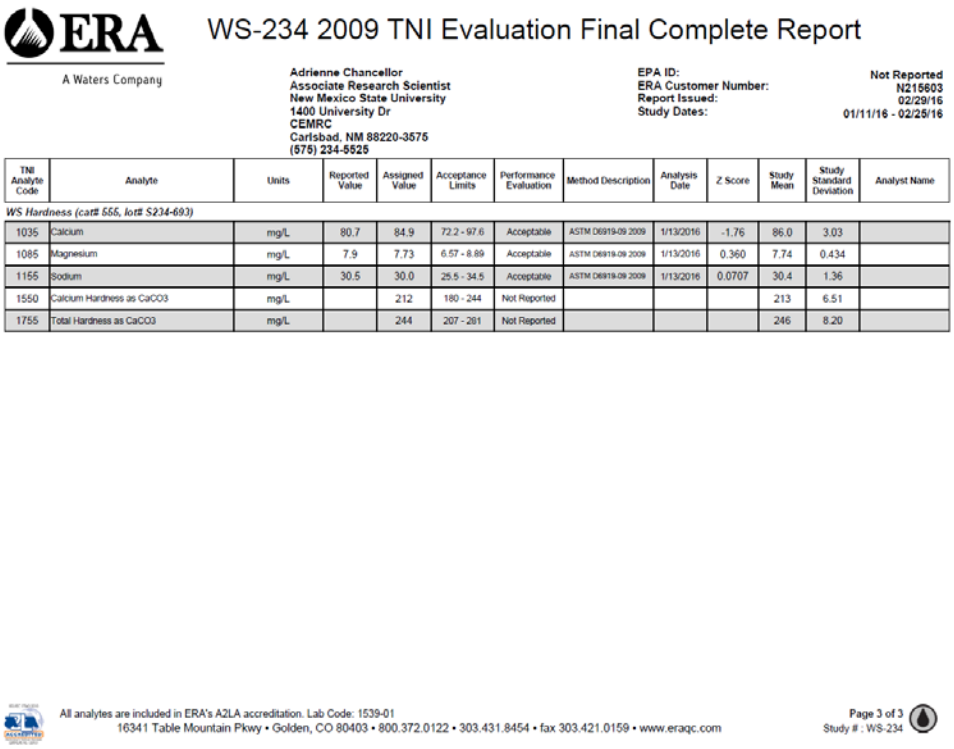
Study # : WS-235

Figure 9-7a: Blind Checks for Environmental Chemistry Inorganic Analyses



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WS-234 2009 TNI Evaluation Final Complete Report

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EPA ID: Not Reported
ERA Customer Number: N215603
Report Issued: 02/29/16
Study Dates: 01/11/16 - 02/25/16

TNI Analyte Code	Analyte	Units	Reported Value	Assigned Value	Acceptance Limits	Performance Evaluation	Method Description	Analysis Date	Z Score	Study Mean	Study Standard Deviation	Analyst Name
WS Hardness (cat# 555, lot# S234-693)												
1035	Calcium	mg/L	80.7	84.9	72.2 - 97.6	Acceptable	ASTM D6919-09 2009	1/13/2016	-1.76	86.0	3.03	
1085	Magnesium	mg/L	7.9	7.73	6.57 - 8.89	Acceptable	ASTM D6919-09 2009	1/13/2016	0.360	7.74	0.434	
1155	Sodium	mg/L	30.5	30.0	25.5 - 34.5	Acceptable	ASTM D6919-09 2009	1/13/2016	0.0707	30.4	1.36	
1550	Calcium Hardness as CaCO3	mg/L		212	180 - 244	Not Reported				213	6.51	
1755	Total Hardness as CaCO3	mg/L		244	207 - 281	Not Reported				246	8.20	

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Page 3 of 3
Study # : WS-234

Figure 9-7a: Blind Checks for Environmental Chemistry Inorganic Analyses (continued)

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WS-236 2009 TNI Evaluation Final Complete Report

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EPA ID: Not Reported
ERA Customer Number: N215603
Report Issued: 04/19/16
Study Dates: 03/01/16 - 04/15/16

TNI Analyte Code	Analyte	Units	Reported Value	Assigned Value	Acceptance Limits	Performance Evaluation	Method Description	Analysis Date	Z Score	Study Mean	Study Standard Deviation	Analyst Name
WS Metals (cat# 590, lot# S236-697)												
1000	Aluminum	µg/L	860.4	809	688 - 930	Acceptable	EPA 200.8 5.4 1994	4/8/2016	1.20	809	42.4	
1005	Antimony	µg/L	21.7	22.2	15.5 - 28.9	Acceptable	EPA 200.8 5.4 1994	4/8/2016	-0.334	22.2	1.44	
1010	Arsenic	µg/L	16.2	16.0	11.2 - 20.8	Acceptable	EPA 200.8 5.4 1994	4/8/2016	0.138	16.0	1.13	
1015	Barium	µg/L	1354.0	1350	1150 - 1550	Acceptable	EPA 200.8 5.4 1994	4/8/2016	0.270	1340	50.5	
1020	Beryllium	µg/L	5.4	4.93	4.19 - 5.67	Acceptable	EPA 200.8 5.4 1994	4/8/2016	1.34	4.91	0.365	
1025	Boron	µg/L		1760	1500 - 2020	Not Reported				1760	94.8	
1030	Cadmium	µg/L	5.5	5.40	4.32 - 6.48	Acceptable	EPA 200.8 5.4 1994	4/8/2016	-0.117	5.55	0.406	
1040	Chromium	µg/L	170.2	168	143 - 193	Acceptable	EPA 200.8 5.4 1994	4/8/2016	0.362	167	7.64	
1055	Copper	µg/L	445.3	429	386 - 472	Acceptable	EPA 200.8 5.4 1994	4/8/2016	0.985	426	19.2	
1070	Iron	µg/L	1808.0	1730	1470 - 1990	Acceptable	EPA 200.8 5.4 1994	4/8/2016	1.11	1730	69.5	
1075	Lead	µg/L	55.4	50.4	35.3 - 65.5	Acceptable	EPA 200.8 5.4 1994	4/8/2016	1.65	50.2	3.13	
1090	Manganese	µg/L	425.0	407	346 - 468	Acceptable	EPA 200.8 5.4 1994	4/8/2016	0.467	415	22.2	
1100	Molybdenum	µg/L	55.5	58.8	50.0 - 67.6	Acceptable	EPA 200.8 5.4 1994	4/8/2016	-0.591	57.2	2.87	
1105	Nickel	µg/L	124.7	127	108 - 146	Acceptable	EPA 200.8 5.4 1994	4/8/2016	-0.479	128	5.88	
1140	Selenium	µg/L	44.0	50.5	40.4 - 60.6	Acceptable	EPA 200.8 5.4 1994	4/8/2016	-1.47	49.6	3.83	
1150	Silver	µg/L	131.5	133	93.1 - 173	Acceptable	EPA 200.8 5.4 1994	4/8/2016	-0.223	133	5.15	
1165	Thallium	µg/L	7.9	7.05	4.94 - 9.16	Acceptable	EPA 200.8 5.4 1994	4/8/2016	1.62	6.97	0.576	
1185	Vanadium	µg/L	718.2	681	579 - 783	Acceptable	EPA 200.8 5.4 1994	4/8/2016	0.963	676	44.1	
1190	Zinc	µg/L	1482.7	1480	1260 - 1700	Acceptable	EPA 200.8 5.4 1994	4/8/2016	-0.0513	1490	88.9	

All analytes are included in ERA's A2LA accreditation. Lab Code: 1539-01
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Study # : WS-236

Figure 9-7b: Blind Checks for Environmental Chemistry Inorganic Analyses

CONCLUSION

Almost three years ago, the Waste Isolation Pilot Plant (WIPP) experienced its first minor accident involving an underground radiological release. Late in the evening on February 14, 2014 a waste container in the repository underwent a chemical reaction that caused the container to overheat and breach, releasing its contents into the underground. Following a lengthy recovery process the facility recently resumed waste disposal operations. The accident released significant levels of radioactivity into the disposal room and adjacent exhaust drifts and although no one was present in the underground at the time of the release, a total of 22 workers tested positive for very low levels of radiation, presumably from some of the radioactive material that was released above ground through a small leak in the bypass circuit of the HEPA filtration system. The dominant radionuclides released were ^{241}Am and $^{239+240}$Pu in a ratio that matched the content of the drum from the Los Alamos National Laboratory (LANL) that was eventually identified as the breached container. From the air particulate monitoring and plume modeling conducted by the DOE, it was concluded that the dose, at the nearest location accessible to the general public, from this radiation release event would have been less than 0.01 mSv (<1 mrem/year). This level is well below the 0.1 mSv/year (10 mrem/year) regulatory limit for DOE facilities established by the U.S. Environmental Protection Agency (US-EPA).

This contamination was detected by the CEMRC approximately one kilometer away from the facility a few days after the incident. The highest activities detected outside were 115.2 µBq/m^3 for ^{241}Am and 10.2 µBq/m^3 for $^{239+240}$Pu at a sampling station located 91 meters away from the underground air exhaust point and 81.4 µBq/m^3 of ^{241}Am and 5.8 µBq/m^3 of $^{239+240}$Pu at a monitoring station located approximately one kilometer northwest of the WIPP facility. A week after the event, the radiation at these stations had decreased by a hundred times, and two weeks later the radiation levels at these stations were back to the pre-release levels and sometimes not even detectable, demonstrating no continuing or long-term environmental contamination. According to source-term estimates, the actual amount of radioactivity released from the WIPP site was less than 1.5 millicurie (mCi).

In the wake of the underground radiation release incident of February 14, 2014, the CEMRC conducted an extensive monitoring and measurement campaign to assess the level of risk to anyone as a result of the WIPP underground radiation release event and/or from the on-going WIPP-related activities in general. Moving forward, the CEMRC has continued its efforts to conduct accelerated analyses of the WIPP underground air filters collected from Stations A and B, as well as ambient air samples, and other environmental samples collected in and around the WIPP facility in 2016. Sampling during 2016 was in large part returned to the pre-event schedule, with no detections of radioactivity found to be attributable to WIPP-related operations. Monitoring results continue to be made accessible to the public as soon as they become available. Throughout 2016, town hall meetings were conducted regularly to inform the community of the status of the WIPP recovery and restart activities and to provide an

opportunity for the public to communicate directly with DOE and WIPP management. Access was also provided via Live-Stream video maintained on the WIPP Recovery Website (http://wipp.energy.gov/wipprecovery/recovery.html). This timely dissemination of information is important in terms of assuring the local public that the potential health impacts of radiation from the WIPP facility are being independently evaluated and to provide the public with a basis for judging the continued acceptability of this facility.

Another capability developed by the CEMRC as part of its service to the southeastern New Mexico region is a program called "Lie Down and Be Counted". This program uses a state of the art whole body counting system that can measure the body burden of radioactive elements at extremely low levels and has operated over the past 15 years with over 1,400 local residents participating to form a baseline. Following the radiation release event, the CEMRC continued to offer this free lung and whole body counting service to adult citizens living within a 100-mile radius of the WIPP facility seven days a week. Concerned citizens were encouraged to be measured to see what radiation might exist in their lungs and whole body. Even though there was not a substantial upsurge in the number of citizens who took advantage of this valuable service, just the mere availability of such a service, provided a sense of security to concerned citizens after the event.

The CEMRC's recent monitoring data show that the concentration levels of the radionuclides of concern present in the environment have returned to normal background levels and in many instances, are not even detectable, demonstrating no long-term environmental impacts of the recent radiation release event at the WIPP. ***Further, an evaluation of 2016 environmental monitoring data indicates that WIPP operations have been safe and that the levels of radiation that escaped to the environment from the 2014 radiation release event were very low and did not, and will not, harm anyone or have any long-term environmental consequence.*** In terms of radiological risk at or in the vicinity of the WIPP site, the increased risk from the WIPP release is exceedingly small, approaching zero.

For an established radioactive waste management or disposal facility the challenge is to maintain that public support as generations pass and as local populations change. To ensure the continued public support for the operation of nuclear facilities, it is necessary to increase public trust by actions that lead to a generalized improvement in the safety at nuclear facilities and by a better risk communication with the public. An accident tests the facility's relationship with the public. Following the radiation release event at WIPP, the information and outreach provided to local citizens by the CEMRC played a crucial role in allaying the concerns of local citizens residing in Carlsbad about the recent radiation release from their nearby repository. It is unlikely they would have had the same level of trust in an outside agency's assurances of safety. Over the years of its existence the CEMRC's independence and its extensive monitoring program and public engagement have aided the continuing acceptance of this nearby nuclear facility. The credibility that the CEMRC has established over time is such that there would have been confidence in the

public that if the release levels had posed a risk to the local or regional public, as the CEMRC would have told them so. This timely dissemination of information was and remains important for assuring the local public that the potential health impacts of the recent radiation release from the WIPP are being independently evaluated, and provides the public a basis for judging the continued acceptability of this facility. Therefore, a community currently considering hosting an interim storage or permanent disposal site should include an independent monitoring and communications program as part of the infrastructure needed to assure local acceptance of planned repositories elsewhere in the nation or the world.

Appendices

The following information is provided to assist the reader in understanding this report. Included here is information on scientific notation, radioactivity units, understanding data tables and data uncertainty, understanding graphs, and selected mathematical symbols.

Scientific Notation

Scientific notation is used to express very large or very small numbers. For example, the number 1 billion could be written as 1,000,000,000 or, by using scientific or E notation, written as 1×10^9 or 1.0E+09. Translating from scientific notation to a more traditional number requires moving the decimal point either left or right from its current location. If the value given is 2.0×10^3 (or 2.0E+03), the decimal point should be moved three places to the **right** so that the number would then read 2,000. If the value given is 2.0×10^{-5} (or 2.0E-05), the decimal point should be moved five places to the **left** so that the result would be 0.00002.

Radioactivity Units

Much of this report provides data on levels of radioactivity in various environmental media. Radioactivity in this report is usually discussed in units of **curies (Ci)**, with conversions to **becquerels (Bq)**, the International System of Units measure (Table 1). The curie is the basic unit used to describe the amount of activity present, and activities are generally expressed in terms of curies per mass or volume (e.g., picocuries per liter). One curie is equivalent to 37 billion disintegrations per second or is a quantity of any radionuclide that decays at the rate of 37 billion disintegrations per second. One becquerel is equivalent to one disintegration per second. Nuclear disintegrations produce spontaneous emissions of alpha or beta particles, gamma radiation, or various combinations of these.

Understanding the Data Tables

Some degree of variability, or uncertainty, is associated with all analytical measurements. This uncertainty is the consequence of random or systematic inaccuracies related to collecting, preparing, and analyzing the samples. These inaccuracies could include errors associated with reading or recording the result, handling or processing the sample, calibrating the counting instrument, and numerical rounding. With radionuclides, inaccuracies can also result from the randomness of radioactive decay. In this report, the uncertainties used include standard deviation, total propagated analytical uncertainty, and standard error of the mean.

Table 1: Names and symbols for Units of Radioactivity			
Symbol	Name	Symbol	Name
Ci	curie	Bq	becquerel (2.7×10^{-11} Ci)
mCi	millicurie (1×10^{-3} Ci)	kBq	kilobecquerel (1×10^{3} Bq)
µCi	microcurie (1×10^{-6} Ci)	MBq	megabecquerel (1×10^{6} Bq)
nCi	nanocurie (1×10^{-9} Ci)	mBq	millibecquerel (1×10^{-3} Bq)
pCi	picocurie (1×10^{-12} Ci)	GBq	gigabecquerel (1×10^{9} Bq)
fCi	femtocurie (1×10^{-15} Ci)	TBq	terabecquerel (1×10^{12} Bq)

Standard Deviation

The standard deviation (SD) of sample data relates to the variation around the mean of a set of individual sample results. If differences in analytical results occur among samples, then two times the standard deviation (or ±2 SD) implies that 95% of the time, a re-count or re-analysis of the same sample would give a value somewhere between the mean result minus two times the standard deviation and the mean result plus two times the standard deviation.

Total Propagated Analytical Uncertainty

For samples that are prepared or manipulated in the laboratory prior to counting (counting the rate of radioactive emissions from a sample), the total propagated analytical uncertainty includes both the counting uncertainty and the uncertainty associated with sample preparation and chemical separations. For samples that are not manipulated (e.g., ashed, dried, or chemically treated) in the laboratory before counting, the total propagated analytical uncertainty only accounts for the uncertainty associated with counting the sample. The uncertainty associated with samples that are analyzed but not counted (e.g., chemical or water quality measurements) includes only the analytical process uncertainty. In this situation, the total propagated analytical uncertainty is assumed to be the nominal detection limit.

Standard Error of the Mean

Just as individual values are accompanied by counting uncertainties, the mean of mean values (averages) is accompanied by ±2 times the standard error of the calculated mean. Two times the standard error of the mean implies that approximately 95% of the time the next calculated mean will fall somewhere between the reported value minus two times the standard error and the reported value plus two times the standard error.

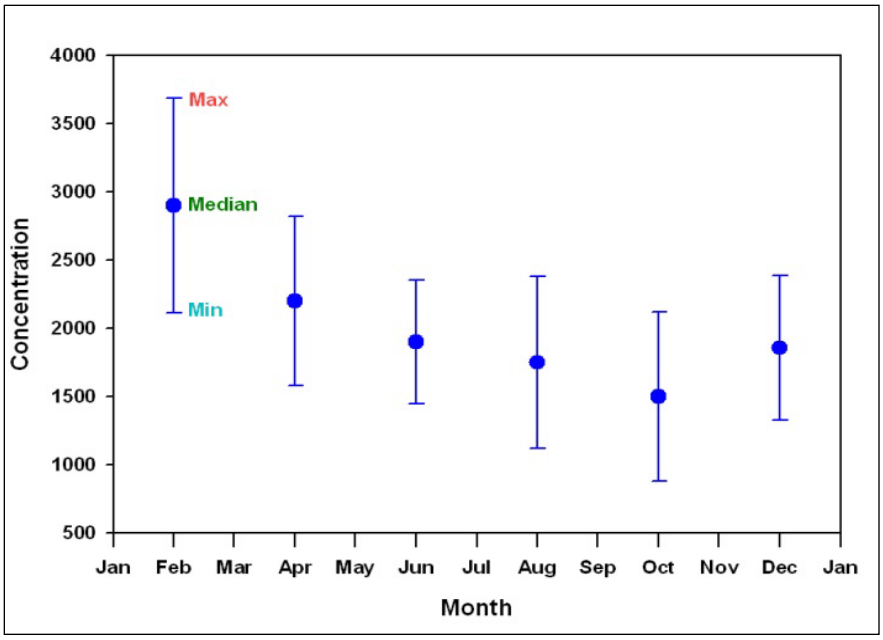

Figure A-1: Graphical representation of maximum, median and minimum values

Median, Maximum, and Minimum Values

Median, maximum, and minimum values are reported in some sections of this report. A median value is the middle value of an odd numbered set and the average of the two central values in an even numbered set. For example, the median value in the odd numbered series of numbers - 1, 2, 3, 3, 4, 5, 5, 5, 6 is 4. The maximum value would be 6 and the minimum value would be 1. Median, maximum, and minimum values are reported when there are too few analytical results to accurately determine the average with a ± statistical uncertainty or when the data do not follow a bellshape (i.e., normal) distribution. Figure A-1 provides a graphical representation of median, maximum, and minimum values. The upper line is the maximum value, the center dot is the median value, and the lower line is the minimum value.

Negative Concentrations

Instruments used in the laboratory to measure radioactivity in WIPP Site environmental samples are sensitive enough to measure natural, or background, radiation along with any contaminant radiation in a sample. To obtain a true measure of the contaminant level in a sample, the background radiation level must be subtracted from the total amount of radioactivity measured by an instrument. Because of the randomness of radioactive emissions, the very low activities of some contaminants, or the presence of undesirable materials, it is possible to obtain a background measurement that is larger than the actual contaminant measurement. When the larger background measurement is subtracted from the smaller contaminant measurement, a negative result is generated. The negative results are reported because they are essential when conducting statistical evaluations of the data.

Understanding Graphs

Graphs are useful when comparing numbers collected at several locations or at one location over time. Graphs often make it easy to visualize differences in data where they exist. However, careful consideration should be given to the scale (linear or logarithmic) and units. Some of the data graphed in this report may be plotted using logarithmic, or compressed, scales.

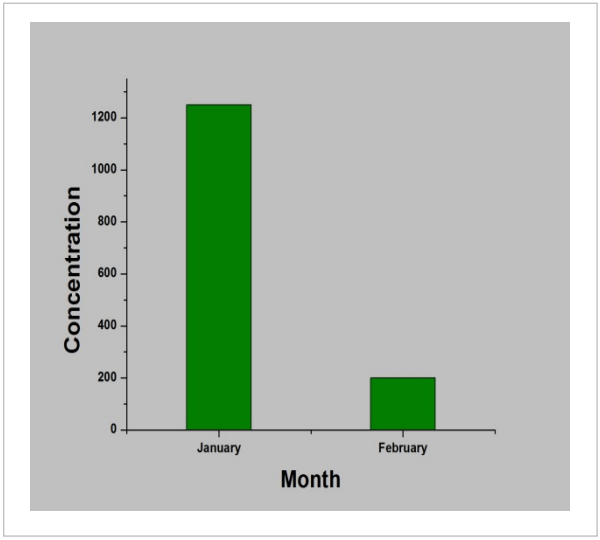

Figure A-2: Data plotted using a linear scale

Logarithmic scales are useful when plotting two or more numbers that differ greatly in size or are very close together. For example, a sample with a concentration of 5 grams per liter would get lost at the bottom of the graph if plotted on a linear scale with a sample having a concentration of 1,000 grams per liter (Figure A-2). A logarithmic plot of these same two numbers allows the reader to see both data points clearly (Figure A-3).

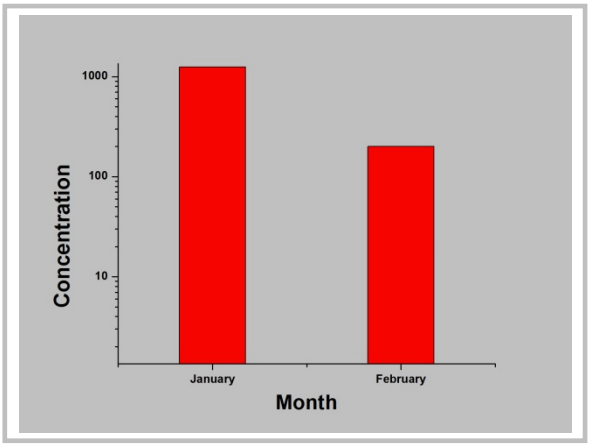

Figure A-3: Data plotted using a logarithmic

The mean (average) and median (defined earlier) values seen in graphics in this report have vertical lines extending above and below the data point. When used with a value, these lines (called error bars) indicate the amount of uncertainty (standard deviation, total propagated analytical uncertainty, or two standard error of the mean) in the reported value.

The error bars in this report represent a 95% chance that the value is between the upper and lower ends of the error bar and a 5% chance that the true value is either lower or higher than the error bar. For example, in Figure A-4, the first plotted value is 2.0 ± 1.1, so there is a 95% chance that the true value is between 0.9 and 3.1, a 2.5% chance that it is less than 0.9, and a 2.5% chance that it is greater than 3.1. Error bars are computed statistically, employing all of the information used to generate the value. These bars provide a quick, visual indication that one value may be statistically similar to or different from another value. If the error bars of two or more values overlap, as is the case with values 1 and 3 and

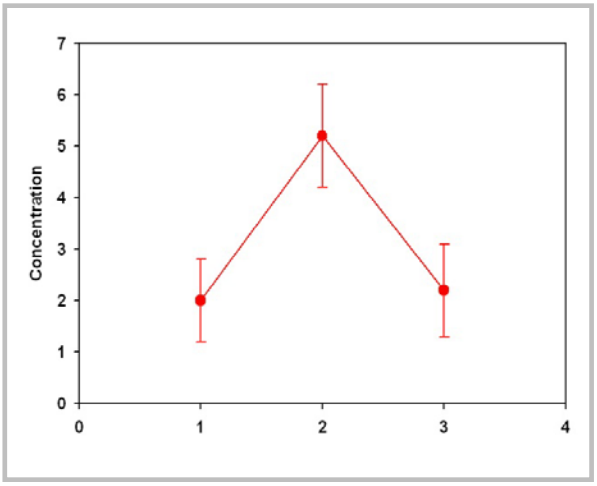

Figure A-4: Data with error bars plotted using a linear scale

values 2 and 3, the values may be statistically similar. If the error bars do not overlap (values 1 and 2), the values may be statistically different. Values that appear to be very different visually (values 2 and 3) may actually be quite similar when compared statistically. Lastly, when vertical lines are used with median values, the lower end of each bar represents the minimum concentration measured while the upper end of each bar represents the maximum concentration measured (see Figure A-1).

References

Ahrens, L.H., (1965). Some observation on the uranium and thorium distributions in accessory zircon from granitic cocks. Geochim. Cosmochima. Act. 29:711-716.

Alirezazadeh N, Garshasbi H (2003). A survey of natural uranium concentrations in drinking water supplies in Iran. Iran. J. Radiat. Res 1:139-142.

Alberts, J.J., Bobula, C.M., & Farrar, T. (1980). A comparison of the distribution of industrially released ^{238}Pu and Fallout ^{239,240}Pu in temperate, Northern United States soils. *Journal of Environmental Quality,* 9: 592-596

Alto, B.R., R.S. Fulton (1965). "Salines" and "The potash Industry" in Mineral and Water Resources of New Mexico, New Mexico Bureau of Mines and Mineral Resources, Bulletin 87, p.299-309.

Arimoto, R. and the Effluent Monitoring Improvement Group. (2006). *In situ Aerosol probe Occlusion Tests at the Waste Isolation Pilot Plant.* Abstract TAM-A.9, Book of Abstracts, 51st Annual Meeting of the Health Physics Society. Providence, RI.

Arimoto, R., J. B. Webb, & M. C. Conley. (2005). Radioactive contamination of atmospheric dust over southeastern New Mexico, *Atmospheric Environment*, 39: 4745-4754.

Arimoto, R., Kirchner, T. B. , Webb, J. L., Conley, M. C., Stewart, B., Schoep, D. & Walthall, M. (2002). 239,240Pu and inorganic substances in aerosols from the vicinity of the Waste Isolation Pilot Plant: The importance of Resuspension. *Health Physics Journal*, 83:456-470.

Banks, D., Royset, O., Strand, T., Skarphagen, H. (1995).Radioelement (U, Th, Rn) concentrations in Norwegian bedrock groundwaters. Environ. Geol. 25: 165-180.

Beck, H. L. & Bennet, G.B. (2002). Historical overview of atmospheric nuclear weapon testing and estimates of fallout in the continental United States. *Health Physics*, 82:591-608.

Bou-Rabee, F. (1995). Estimating the concentration of uranium in some environmental samples in Kuwait after the 1991 Gulf War. Appl. Radiat. Isot. 46: 217-220.

Brown, A., Steenfelt, A., Kunzzenorf, H. (1983). Uranium districts defined by reconnaissance geochemistry in South Greenland. J. Geochem. Explor. 19:127-145.

Bennett B.G. (1978). Environmental Aspects of Americium. Rep. EML-348, Environmental Measurements Laboratory, U.S. Department of Energy, New York, New York.

Castillo, H., Schoederbek D., Dhulal S., Escobar G., Wood, J., Nelson R., and Smith, G.B., (2015). Stress induction in the bacteria *Shewanella oneidensis* and *Deinococcus radiodurans* in response to below-background ionizing radiation. 2015. *International Journal of Radiation Biology*. 91:749-756.

CEMRC, Carlsbad Environmental Monitoring & Research Center, *1996 Report*. Carlsbad, New Mexico.

CEMRC, Carlsbad Environmental Monitoring & Research Center, *1998 Report*. Carlsbad, New Mexico.

CEMRC, Carlsbad Environmental Monitoring & Research Center, *2000 Report*. Carlsbad, New Mexico.

CEMRC, Carlsbad Environmental Monitoring & Research Center, *2005/2006 Report*. Carlsbad, New Mexico.

CEMRC, Carlsbad Environmental Monitoring & Research Center, *2011 Report*. Carlsbad, New Mexico.

CEMRC, Carlsbad Environmental Monitoring & Research Center, *2012 Report*. Carlsbad, New Mexico.

Cherdynstev, V.V. (1971) Uranium-234. Program for scientific translations Ltd. Keter Press, Jerusalem, p. 234.

Chugg, J.C., Anderson, J.W., King, D.L., Jones, L.H. (1971) Soil survey of Eddy County, New Mexico, Washington DC., US Department of Agriculture.

Cothern, C.R., Lappenbusch, W.L., (1983) Occurrence of uranium in drinking water in the US. Health Phys 45:89–99.

Conca, J., T. Kirchner, J. Monk, S. Sage, WM2008 Conference, 2008, Phoenix, AZ, Long-Term Environmental Monitoring of an Operating Deep Geologic Nuclear Waste Repository – 8184.

DOE/WIPP-92-037, (1992). *Statistical Summary of the Radiological Baseline for the Waste Isolation Pilot Plant*. Waste Isolation Pilot Plant, Carlsbad, NM.

DOE/WIPP-95-2065, (1997). *Waste Isolation Pilot Plant Safety Analysis Report*. Revision 1, March, Carlsbad, NM.

DOE/EH-0173T, (1991). *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*.

DOE, 2014a. U.S. Department of Energy- Accident Investigation Board (AIB) Report, Underground Salt Haul Truck Fire at the Waste Isolation Pilot Plant, February 5, 2014. Washington, DC: U.S. Department of Energy. Accessible at: http://www.wipp.energy.gov/Special/AIB%20Report.pdf

DOE, 2014b. U.S. Department of Energy Accident Investigation Report, Phase-I. Radiological Release Event at the Waste Isolation Pilot Plant on February 14, 2014. Washington, DC: U.S. Department of Energy. Accessible at: http://www.wipp.energy.gov/Special/AIB_Final_WIPP_Rad_Release_Phase1_04_22_2014.pdf

DOE, 2015. U.S. Department of Energy Accident Investigation Report, Phase -II. Radiological Release Event at the Waste Isolation Pilot Plant on February 14, 2014. Washington, DC: U.S. Department of Energy. Accessible at:http://www.wipp.energy.gov/Special/AIB_WIPP%20Rad_Event%20Report_Phase%20II.pdf

EFSA Uranium in foodstuffs, in particular mineral water. Scientific Opinion of the Panel on Contaminants in the Food Chain. [August 2011]; The European Food Safety Authority (EFSA) Journal. 2009 1018:1–59. 2009.http://www.efsa.europa.eu/en/scdocs/doc/1018.pdf.

Faller, S (1994). *Residual soil radioactivity at the Gnome Test Site in Eddy County, New Mexico, Report No. EPA 600/R-94/117*, July 1994. Washington, D.C., Environmental Protection Agency.

Firestone, R.B. (1998). *Table of Isotopes*. John Wiley & Sons, New York.

Fleischer, R.L. (1980). Isotopic disequilibrium of uranium: alpha-recoil damage and preferential solution effects. Science 207:979–981.

Gedeon, R, Smith B, Amro H, Jawadeh J. (1994). Natural radioisotopes in groundwater from the Amman-Zarka basin Jordan. Hydrochemical and regulatory implications. Applications of tracers in arid zone hydrology. Wallingford, UK: IAHS Press. IAHS Publication 232:1994.

Gegner, M., Irlweck K. (2005). Uranium concentrations and isotopic ratios in Austrian drinking waters. Radioactivity in the Environment. 7:135-139.

Griffith, J., Willcox, S., Power, D., Nelson, R., Baxter, B., (2008). Discovery of abundant cellulose microfibers encased in 250 Ma Permian halite: a macromolecular target in the search for life on other planets. Astrobiology 8: 1-14.

Gross, M., S. Patchet, J. Davis, D. Ferguson, and R. Elmore (2011). Representativeness of Sampling by Shrouded Probes in the Exhaust Shaft of the Waste Isolation Pilot Plant, Paper 11308 at WM2011 Conference, February 27 – March 3, 2011, Phoenix, AZ. Accessible at: http://www.wmsym.org/archives/2011/papers/11308.pdf

Gilkeson RH, Coward JB. A preliminary report on U-238 series disequilibrium in ground water of the Cambriam-Ordovician aquifer system of Northeastern Illinois (1992). In: Perry EC, Montgomery CW (ed) Isotope studies of hydrologic processes, Northern Illinois University Press, Dekalb. IL, pp.109-118.

Hardy, E.P., Krey, P.W., & Volchok, H.L. (1973). Global inventory and distribution of fallout plutonium. *Nature*, 241:444-445.

Harley, J.H. (1980). Plutonium in the environment-A review. *Journal of Radiation Research*, 21:83-104.

Hess, C.T., Michel, J., Norton, T.R., Prichard, H.M., Coniglio (1985) The occurrence of radioactivity in public water supplies in the United States. Health Phys 48:563–586.

Hodge, V., Smith, C., & Whiting, J. (1996). Radiocesium and plutonium: Still together in "background" soils after more than thirty years. *Chemosphere*, 32:2067-2075.

Kelly, J. M.; Bond, L. A.; & Beasley, T. M. (1999). Global distribution of Pu isotopes and ^{237}Np. *Sci. Tot. Environ.* 237/238:483-500.

Kenney, J.W., Downes, P.S. Gray, D.H. & Ballard, S.C. (1995). Radionuclide baseline in soil near project Gnome and the Waste Isolation Pilot Plant. Environmental Evaluation Group, EEG-58

Kerr, R. A. (1999). "For Radioactive Waste from Weapons, a Home at Last," Science, 283:5408. https://doi.org/10.1126/science.283.5408.1626

Kirchner, T.B., Webb, J.L., Webb, S.B., Arimoto, R., Schoep, D. & B.D. Stewart. (2002). Variability in background levels of surface soil radionuclides in the vicinity of the US DOE waste isolation pilot plant. *J. Environ. Radioact.*60: 275-291.

Kozlowska B, Walencik A, Dorda J, Przylibski TA (2007) Uranium, radium and ^{40}K isotopes in bottled mineral waters from Outer Carpathians, Poland. Radiat Meas 42:1380-1386.

Kumru MN (1995) Distribution of radionuclides in sediments and soils along the Büyük Menderes River. Proc. of the Pakistan Academy of Sciences, 32:51-56.

Krey, P.W. (1967). Atmospheric Burnup of a Plutonium-238 generator. *Science*, 158:769-771.

Krey, P.W., Beck, H.L., *The distribution throughout of Utah of ^{137}Cs and $^{239+240}$Pu from Nevada Test Site detonations.* US Department of Energy, Environmental Laboratory, EML-400 (1981).

Kuroda, P.K., Essien, I.O., & Sandoval, D.N. (1984). Fallout of uranium isotopes from the 1980 eruption of Mount St. Helens. *Journal of Radioanalytical Nuclear Chemistry*, 84, 23-32. (Cited in ATSDR 1999).

Lee, S.C., Webb J.L., Fingleton, D.J. (1996). Determination of baseline atmospheric Pu-239, 240 in the vicinity of the Waste Isolation Pilot Plant. 42nd Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, San Francisco, CA.

MacIntosh D., Ozkaynak, H., Fingleton, D.J. (1993). Atmospheric Monitoring in the vicinity of radioactive Waste Repositories. 39th Annual conference on Bioassay, Analytical and Enviroemtnal Radiochemistry, Colorado Springs, CO

Melaku, S., Morris, V., Raghavan, D. & Hosten, C. (2008). Seasonal variation of heavy metals in ambient air and precipitation at a single site in Washington, DC. *Environmental Pollution,* 155: 88-98.

Mereiter, K. (1979). Refinement of the Crystal Structure of Langbeinite, K2Mg2(SO4)3. Neues Jahrb. Mineral., Monatsh., 182–188.

Minnema, D. M., & Brewer, L.W. (1983). *Background Radiation Measurements at Waste Isolation Pilot Plant Site*. SAND83-1296. Sandia National Laboratories, Carlsbad, NM.

National Council on Radiation Protection and Measurements. (1984). Exposures from the uranium series with emphasis on radon and its daughter, Protection and Measurements (NCRP Report No. 77:56-68). (Cited in ATSDR 1999).

National Council on Radiation Protection and Measurements. 2009. *Ionizing Radiation Exposure of the Population of the United States*. NCRP Report No. 160, Washington, D.C.

OMEE-Ontario drinking water surveillance program, 1996.

Palache, C., H. Berman, and C. Frondel (1951) Dana's System of Mineralogy, (7th edition), v. II, 434-435.

Perkins, R.W., Thomas, C.W. (1980). Worldwide fallout. In: Hanson WC (ed) Transuranic elements in the environment. Technical Information Center, U.S. Department of Energy, Springfield, pp 53-82.

Pillalamarri, I., Jagam, P. (2015). Consideration of the Interference from ^{40}K Internal to the Human Body for the Setting up of a Low Background Whole Body Counter (WBC) for Internal Dosimetry at the Waste Isolation Pilot Plant (WIPP) Carlsbad, NM, USA (Simulations performed using GEANT, 2014-2015).

Pillalamarri, I., Jagam, P. (2015). Further considerations for the setting up of a low background whole-body counter for internal dosimetry at Waste Isolation Pilot Plant (WIPP) Carlsbad, NM, USA: Transmitted photon component. Radiation Protection Dosimetry, 164(3), 271-7; DOI: 10.1093/rpd/ncu267.

Pillalamarri, I., Jagam, P., Lykken, G. I., (2013). Internal Dosimetry of ^{210}Pb In The Human Cranium: Preliminary Results From Instrumentation Needs For In Vivo Counting In A Low-Background Underground Counting Facility. Radiation Protection Dosimetry, 57(1), 6-10. DOI: 10.1093/rpd/nct109.

Pimple, M., Yoo, B., Yordanova, L. (1992) Optimization of a radioanalytical procedure for the determination of uranium isotopes in environmental samples. J. Radioanal. Nucl. Chem. Articles 161:437–441.

Plater, A.J., Ivanovich, M., & Dugdale R.E. (1992). Uranium series disequilibrium in river sediments and waters: the significance of anomalous activity ratios. *Applied Geochemistry*, 7:101-110

Recovery web site, accessed 09-29-2015. http://www.wipp.energy.gov/Special/Station%20B.pdf

Roback, R.C., Johnson, T. M., McLing, T., Murrell, M.T., Luo, S., T.L. Ku., (2001) Uranium isotopic evidence for groundwater chemical evolution and flow patterns in the eastern Snake River Plain aquifer, Idaho GSA Bulletin, 113: 1133-1141.

Romney, E.M., Hunter, R.B., Wallace, A (1987) Distribution of $^{239+240}$Pu, ^{241}Am, ^{137}Cs, and ^{90}Sr on vegetation at nuclear site 201, 219, and 221. In Howard, W.A and Fuller R.G (Eds.). The dynamics of transuranic and other radionuclides in natural environments, Springfield, VA, USDOE Report NVO-272, USDOE, NTIS.

Rosner, G., Hotzl, H., Winkler, R. (1997). Long term behavior of plutonium in air and deposition and the role of resuspension in a semi-rural environment in Germany. Sci. Total Environ. 196, 255-261.

Sehmel, G.A (1987) Transuranic resuspension. In Pinter JE, III, Alberts J.J., McLeod, K.W.R.G. Schreckhise, (eds.) Environmental research on actinide elements. Washington, DC: Office of Science and Technical Information; CONF-841142, 157-192.

Skwarzec, B.; Boryło, A., Strumin´ska, D. (2002) ^{234}U and ^{238}U isotopes in water and sediments of the southern Baltic. J. Environ. Radioact., 61:345–363.

Smith, G.B., Yair G., Navarette, A., Guilmette., R.A., (2011). Exploring biological effects of low level radiation from the other side of background. Health Physics. 100:263-265.

Stout, J.E., Arimoto, R. (2010). Threshold wind velocities for sand movement in the Mescalero Sands of southeastern New Mexico, J. of Arid Environ. 74:1456-1460.

SOTERM (2014). Title 40 CFR Part 191 Subparts B and C Compliance Recertification Application 2014.*DOE|WIPP-14-3503*. SOTERM-iii. *Appendix SOTERM-2014*.

Turner, M.T., Cox, D.N., Mickelson, B.C., Roath, A.J., Wilson, C.D. (1974) Soil Survey of Lea County New Mexico, Washington DC., US Department of Agriculture.

Tyndall, J. (1877). Further researches on the deportment and vital persistence of putrefactive and infective organisms from a physical point of view. *Phil. Tran. Royal Soc. of London*. 167:149-206. Article translated by T.D. Brock , 1961. *Milestones in Microbiology*. Prentice Hall.

U.S. Congress (1992). The Waste Isolation Pilot Plant Land Withdrawal Act, as amended. Public Law 102-579. Available at: http://www.emnrd.state.nm.us/WIPP/lwa.htm

U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. (1999). *Toxicological Profile for Uranium*. , Atlanta, GA.

U.S. Environmental Protection Agency, Air and Radiation. (1999). *Cancer Risk Coefficients for Environmental Exposure to Radionuclides* (Federal Guidance Report No. 13).

U.S. Environmental Protection Agency. (2012). *National Ambient Air Quality Standards*. Retrieved from http://www3.epa.gov/ttn/naaqs/criteria.html

U.S. Environmental Protection Agency (2012), *Drinking Water Contaminants*, http://water.epa.gov/drink/contaminants/index.cfm#Inorganic).

UNSCEAR (1977). Sources and effects of ionizing radiation. United Nations, New York.

UNSCEAR (1982). Ionizing radiation: Sources and biological effects United Nations Scientific Committee on the Effects of Atomic Radiation New York: United Nations; 1982.

UNSCEAR (2000) United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and effects of ionizing radiation* (2000 Report, Vol. 1).

UNSCEAR (2001). United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and effects of ionizing radiation.* New York: United Nations.

UNSCEAR (2008). Exposures from natural radiation sources. UNSCEAR 2000 Report to the General Assembly, with scientific annexes. United Nations, New York: United Nations Scientific Committee on the Effects of Atomic Radiation

USAEC (1973). United States Atomic Energy Commission. *Gnome/Coach site disposal options*, (NVO-131). Las Vegas, Nevada.

Usman S, Spitz H, Lee S. Analysis of electret ion chamber radon detector response to ^{222}Rn and interference from background gamma radiation. Health Phys. 76, 44-49 (1999).

Vincent, C., Vallon, M., Pinglot, J.F., Funk, M., & Reynaud, L., (1997). Snow accumulation and ice flow at Dôme du Goûter (4300 m), Mont Blanc, French Alps. *Journal of Glaciology,* 43:513-521.

Vreeland, R., Rosenzweig, W., Powers, D., (2000). Isolation of a 250 million-year-old halotolerant bacterium from a primary salt crystal. Nature 407: 897 – 900.

Webb, J.L., Fingleton, D.J., Lee, S.C., Spitz, S.B., (1996). The effect of graded –Z lining and human subjects on low energy background in a courting shield used for lung examinations. Canberra's User's Group meeting, Las Vegas, NV.

Wedepohl, K.H., (1968). Chemical fractionation in the sedimentary environment. In origin and Distribution of the elements, Edited by L.H. Ahrens, 999-1016. New York: Pergamon.

Weeks, J. (2011). "Nuclear Waste Buried for the Ages in New Mexico Desert", CO Researcher 21.4, page 84-85.

WHO (2004). Guidelines for Drinking Water Quality (3rd ed.), World Health Organization, Geneva

WHO (2005). *Uranium in Drinking-water background document*. Guidelines for Drinking Water Quality.