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The Radionuclide Concentration In Dust Collected At The Nellis Dunes Recreational Area

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THE RADIONUCLIDE CONCENTRATION IN DUST COLLECTED AT THE NELLIS DUNES RECREATIONAL AREA

By

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Bachelor of Science - Radiation Health Physics
Oregon State University
2012

A thesis submitted in partial fulfillment of the requirements for the

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Division of Health Sciences
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ABSTRACT

THE RADIONUCLIDE CONCENTRATION IN DUST COLLECTED AT THE NELLIS DUNES RECREATIONAL AREA

By

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Dust Samples were collected from three different locations at the Nellis Dunes Recreation Area, each being of a different soil type. These samples were sieved to different particle sizes and then analyzed using a high-purity germanium gamma well detector. The isotopes found in each sample were: Pb-214, Th-231, Pb-212, Cs-137, and K-40. The activities for these isotopes ranged from: $8.36 \times 10^{-7} \ \mu{Ci/g}$ to $3.11 \times 10^{-6} \ \mu{Ci/g}$, $2.53 \times 10^{-7} \ \mu{Ci/g}$ to $9.98 \times 10^{-7} \ \mu{Ci/g}$, $2.17 \times 10^{-7} \ \mu{Ci/g}$ to $2.51 \times 10^{-7} \ \mu{Ci/g}$, $7.41 \times 10^{-8} \ \mu{Ci/g}$ to $4.22 \times 10^{-7} \ \mu{Ci/g}$, and $7.38 \times 10^{-6} \ \mu{Ci/g}$ to $3.74 \times 10^{-5} \ \mu{Ci/g}$ receptivity. Based on this study and supported by several others, there does appear to be a correlation between not only particle size and radionuclide concentration, but also soil type and radionuclide concentration. Moreover, a lung dose model was created and conservative estimates were performed to calculate a dose for breathing a year’s worth of dust at the Nellis Dunes Recreation Area. The highest possible dose was calculated out to be .0684 rem, which is lower
than the NRC’s annual limit to the general public. Finally, the levels of the Cs-137 were compared to several other locations around the world and the quantities were found to be consistent with global fallout. This means that the proximity that the NDRA has to the Nevada National Security Site does have any noticeable effect on it.
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CHAPTER 1. INTRODUCTION

1.1 The History of Nuclear Weapons Testing

After World War Two More the five declared Nuclear Weapons States: China, France, the United Kingdom, the United States, and the former USSR preformed more than 2,000 nuclear tests. Of these nuclear tests, over 500 have occurred above ground, mostly performed in the 1950s and 1960s, in what were called ‘atmospheric tests’. On October 10, 1963 the Partial Test Ban Treaty (PTBT) or Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water entered into force. Since then more than 1,500 tests were conducted underground, so that these tests would not be as devastating to the environment (Beck, 2002).

1.1.1 Radionuclides Produced from Nuclear Weapons Testing

When a nuclear device is detonated, it leaves behind radioactive material that contains over 150 fissions products with half-lives or with daughters that have half-lives long enough to contribute to fallout.

Table 1. Some of the most important fission, activation nuclides produced in weapons tests. Retrieved from Beck, 2002.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs-137</td>
<td>30.2 y</td>
</tr>
<tr>
<td>Sr-90</td>
<td>28.8 y</td>
</tr>
<tr>
<td>Ru-106</td>
<td>374 d</td>
</tr>
<tr>
<td>Ce-144</td>
<td>285 d</td>
</tr>
<tr>
<td>Zr-95</td>
<td>64 d</td>
</tr>
<tr>
<td>Ba-140</td>
<td>12.8 d</td>
</tr>
<tr>
<td>I-131</td>
<td>8.0 d</td>
</tr>
<tr>
<td>Te-132</td>
<td>3.3 d</td>
</tr>
<tr>
<td>C-14</td>
<td>5730 y</td>
</tr>
<tr>
<td>H-3</td>
<td>12.3 y</td>
</tr>
<tr>
<td>Mn-54</td>
<td>312 d</td>
</tr>
<tr>
<td>Pu-239/240</td>
<td>24110 y</td>
</tr>
<tr>
<td>W-185</td>
<td>74 d</td>
</tr>
</tbody>
</table>
Of these nuclides: $^3$H, $^{14}$C, $^{90}$Sr, $^{137}$Cs, and $^{239/240}$Pu are some of the most important isotopes because they have a long half-life, have the potential to be a health hazard, or they can be used as a tracer (Beck, 2002). Though most of the tests were carried out in remote locations, many were performed above ground and these long-lived isotopes were released into the atmosphere. One such site for atomic testing was the Nevada Test Site--now called the Nevada National Security Site. The Nevada National Security Site was home to 904 nuclear tests starting in January 1951, with 119 of them conducted above ground. Due to all of these tests, large amounts of radionuclides were released into the atmosphere and the surrounding area; these radionuclides are called fallout (Inhaber, 2001).

1.1.2 Fallout and Fallout Dispersal Mechanics

There are a number of factors at play when it comes to calculating the amount of fallout that occurs at varying distances from the site of a nuclear explosion. Some of these factors include the height of the explosion, the total yield and fission yield, the winds at different heights from the ground, the location, and if precipitation is present at different distances. As the fireball cools, less volatile compounds will solidify quicker and will then be incorporated into the large soil particles that have been sucked into the stem of the fireball. These larger particles will settle due to gravity, and therefore, they will settle quickly. The compounds that are more volatile will condense much more slowly and afterwards be deposited onto the surface of particulate debris. Due to the fact that the surface to volume ratio is much larger for smaller particles, the volatile elements have a tendency to attach to these smaller particles that fall to the ground slower and therefore take longer to deposit (Beck, 2002).

Any particles that fall to the ground less than 500 km from the explosion are considered ‘local’ fallout, while particles that reach the ground several thousand kilometers away are considered
intermediate or tropospheric fallout. Finally, debris that is injected into the stratosphere and then widely dispersed before falling to the ground is called ‘global’ fallout (Beck, 2002).

For ‘local’ fallout the height of the burst has a large impact on the total debris produced. For tests near the surface, about one-half of the debris is deposited locally and regionally. For tower shot tests, tests that are performed around 100m above the surface, around 45% of the debris remains close to the test site (Beck, 2002).

Figure 1. Estimated median $^{137}$Cs deposition density (Bq m$^{-2}$) in the United States from all NTS tests. Retrieved from Beck, 2002. Note great lakes are blacked out and not 900 to 1500 Bq/sq. m.

Tropospheric fallout depends strongly on the winds at various heights and distances from the blast. The trajectories of the debris are subject to wind shear. While local fallout is dictated by the gravitational settling of larger particles, as distance increases precipitation becomes a major factor in debris being removed from the atmosphere. For instance, most fallout from the Nevada tests in the eastern United States occurred when the fallout clouds interacted with rain clouds (Beck, 2002).

Once debris is injected into the stratosphere, it can stay there for an extended period of time. The average residence half-life was found to be a little greater than one year. This delay causes
most of the short-lived nuclides to decay away completely. This means that ‘global’ fallout is made of long-lived nuclides such as $^{137}\text{Cs}$, $^{90}\text{Sr}$, and $^{14}\text{C}$ (Beck, 2002). This is one of the ways that man-made radioisotopes are released into the environment.

![Figure 2](image_url)

Figure 2. Estimated deposition-density of $^{137}\text{Cs}$ from global fallout across the continental US. Retrieved from Beck, 2002. Note great lakes are blacked out and not >7500 Bq/sq. m.

### 1.1.3 Production of Naturally Occurring Radioisotopes

Another category of radioisotopes that are also seen in the environment, are naturally occurring radioactive material (NORM). There are mainly three categories of naturally occurring radioisotopes in the environment. The first type is called the primordial radioisotopes. These radioisotopes originated from novas and supernovas that exploded billions of years ago. The radioisotopes created in these explosions have half-lives longer than the age of the Earth and are still detectable today. Three of these primordial radioisotopes are: $^{232}\text{Th}$, $^{238}\text{U}$, and $^{235}\text{U}$. These three radioisotopes are special because they are the starting radioisotopes for their own decay series. Each of these radioisotopes undergo radioactive decay and rather than becoming stable, after one decay, they start a long chain of radioactive decay. These decay series consist of numerous radioactive isotopes that will eventually decay down to a stable isotope. If these parent
nuclides are not disturbed they will be in secular equilibrium with each of their daughters. These radioisotopes and their daughters are present everywhere but especially in rocks and minerals. Another type of primordial radioisotopes are the non-series radioisotopes. There are twenty-two naturally occurring non-series primordial radioisotopes that have been discovered. Of these $^{40}\text{K}$ and $^{87}\text{Rb}$ are the two radionuclides of greatest environmental concern (Krane, 1988).

The third category of naturally occurring radioisotopes in the environment is cosmogenic radioisotopes. These radioisotopes are being produced continuously in our upper atmosphere by high-energy protons (cosmic rays) striking atoms of the atmosphere and causing nuclear reactions. The two most important radioisotopes created this way are $^{14}\text{C}$ and $^{3}\text{H}$. Like the primordial radioisotopes, they are a normal part of our environment (Krane, 1988). Both types of naturally occurring radioisotopes are susceptible to the same forms of re-suspension as man-made radioisotopes are.

Of these two types of radionuclides the important ones for this study are the primordial radioisotopes. Of the primordial radioisotopes the ones that are most likely to show up in gamma spectroscopy are daughters from the Thorium series, daughters from the two Uranium series, and K-40.

1.1.4 Re-suspension of Radioisotopes into the Air

Once radionuclides have settled to the ground, there are numerous ways that they can be lifted back into the air also known as resuspension. One of the primary ways in which this occurs involves the wind. For low wind speeds of around 2-3 m/sec, the smallest radioactive dust particles rise up from the surface of the soil due to random breakthrough of turbulent eddies to the ground. Dust particles smaller 1 to 2 micrometers do not settle under the action of gravity. The larger
particles of radioactive dust are too heavy to remain in the air for a long time. These particles will be lifted into the air by the turbulent eddies and then settle. This is called saltation and is the main mechanism of dust formation as the wind speed increases to a value where wind erosion can occur. Moreover, in arid regions the radioactive dust does not get absorbed into the soil and stays on the top layer of the ground, making it easier to be picked up by the wind (Makhov’ko, 1992).

Human activity also leads to the re-suspension of radioactive dust. There are many ways humans can re-suspend dust such as: driving on the road, construction, electricity generation, fires, fossil fuel combustion, but for the purpose of this study the main focus is off-road driving. Around the world, off-road driving is a prevalent and fast-growing recreational activity on public lands. This activity can badly damage the land in addition to kicking up a large amount of dust. Measurements performed during experiments with off-road vehicles have shown that the concentrations of airborne dust behind and aside an off-road vehicle can be above one million micro grams per meter cubed. This ends up being ten thousand times the natural background. It is reported that driving for only a half hour near an off-road vehicle without protection can result in inhaling an amount of dust equal to the natural annul dose. (Goossens, Buck, and McLaurin, 2012).

1.1.5 Health Concerns Associated with Inhaling Dust

All these forms of re-suspension can lead to human inhalation of radioactive dust. The inhalation of atmospheric dust has been found to cause both cardiovascular and respiratory disease (Morman and Plumelee, 2013). Moreover, because the dust also contains radioactivity, it can lead to internal exposure if inhaled.

Dust particles of any size, but especially dust particles 10 µm in diameter or less, PM10, can have major health impacts. The smaller a particle is, the deeper it is able to penetrate the lungs, and therefore the harder it is to expel. When these particles of matter are inhaled, an increased risk
of cardiovascular and respiratory morbidity, asthma, lung cancer, inflammation, and increased mortality can occur (Morman and Plumelee, 2013). Larger dust particles are less of a concern when considering internal exposure. Larger particles are incapable of penetrating deep into the lungs and will be expelled quickly, through mechanisms such as coughing. This means that the time of exposure will be very small. For instance, only about 29% of particles that are PM60 in the air actually get inhaled, the rest do not even enter the lungs. Moreover, only a small fraction of those particles makes it deeper into the lungs. As the particle size gets smaller a larger percentage is able to penetrate deeper into the lung. This means they will remain in the body for much longer, and the exposure from those particles will be higher, due to a lengthier presence in the lung.

1.1.6 Background on the Nevada National Security Site

The Nevada National Security Site (NNSS) is located in Nye County in southern Nevada. The southernmost point of the NNSS is about 65 miles northwest of Las Vegas. This site consists of about 1,340 square miles of federally owned land with restricted access (Fehncer, 2000).

Public Land Order 805 dated February 19, 1952, allowed for 680 square miles of land to be used for nuclear testing purposes, including an area utilized by the Air Force as a bombing and gunnery range. This area takes up roughly the entire eastern half of the present NNSS. The noticeable geological features of this area are the closed drainage basins of Frenchman Flat and Yucca Flat where the early atmospheric testing occurred (Fehncer, 2000).
Figure 3. Map of the Nevada Test Site and surrounding area. Retrieved from: http://www.nv.doe.gov/library/publications/NTSER/DOENV_11718_1080.pdf
From January 1951 until October 1958, the United States performed around 100 atmospheric nuclear tests at the NNSS. The majority of these tests were low yield devices to test different design concepts. The largest test was a 74 KT test and was performed from a balloon at 400m in July 1957. Around one-half of these tests were done as tower or surfaces shots (Beck 2002).

1.1.7 Background on the Nellis Dunes Recreational Area

The Nellis Dunes Recreational Area (NDRA) is located in the northeastern part of Las Vegas Valley, Clark County. It is run by the Bureau of Land Management and encompasses an area of about 37 km². The Las Vegas Valley is considered an intermountain valley, with mountain ranges in the north and the south. NDRA is located on the eastern side of the valley, between the Sheep Range to the north and the Sunrise and Frenchman Mountains to the south (Goossens and Buck, 2011).
The NDRA has seventeen surface types that known to control dust emissions. These seventeen surface types have then be categorized into four major classes: sand and sand-affect areas; silt/clay areas; rock-covered areas; and zones of bed rock (McLaurin, Goossens, Buck, 2011).
Figure 6. Surface unit map of the Nellis Dunes Recreational Area (McLaurin et al. 2011).

The surface types that produce the most dust due to wind erosion are the sand areas, located in the center and southwest areas of the NDRA. Most of this zone is covered by sand dunes, some of which are partially vegetated with sparse shrubbery. These dunes will produce dust year round through wind erosion. If not disturbed, the silt and drainage areas will only produce a small amount of dust from wind erosion (Goossens, Buck, McLaurin, 2012).

The story changes, however, when off-road vehicles (ORVs) come into play. Off-road vehicle driving is a very popular and fast-growing activity that is done on public lands. The Nellis Dunes Recreational Area is the only public land that is freely accessible for off-road driving. Off-road driving is very popular and the Nellis Dunes Recreation Area has been used for this purpose for the last forty years. In 2008, the Bureau of Land Management in Las Vegas, Nevada, estimated
that over 300,000 people visit per year, which is more than 15% of the population of Las Vegas; use this area for off-road driving (Goossens et al., 2012).

For more than 40 years the Nellis Dunes Recreation Area has been the only publicly accessible area in southern Nevada for off-road driving. Over 530 km of off-road trials have been made, which makes up roughly 6% of the total surface area of the NDRA. Not only do the off road vehicles generate dust when in operation but they destroy the natural surface crust which exposes underlying sediment that will also produce dust during a strong wind (McLaurin et al. 2011).

It has been discovered that the amount of dust created by ORV use in the NDRA is almost the same as the amount of dust created by wind erosion each year (Goossens et al., 2012). It should be noted that the dust production is not uniform across the NDRA. For the most part, most of the dust comes from the areas in the southwest and northwest, while the areas in the center and eastern parts only release small amounts of dust (Goossens et al., 2012).

1.2 Gamma Spectroscopy

When measuring gamma-ray energies above several hundred keV there are two types of detector categories used for gamma-ray spectroscopy: inorganic scintillators and germanium semiconductor detectors. Inorganic scintillators, namely sodium iodide ones, have the advantages of being relatively large and are made of high density material, which allows for a high interaction probability with gamma rays. The high atomic number of iodine also allows for most of the interaction to result in a complete absorption of the gamma-ray energy. The problem with using inorganic scintillators is that the energy resolution is poor (Knoll, 2000).

Germanium detectors, on the other hand, have a much superior energy resolution. A good germanium detector will have an energy resolution of a few tenths of a percent. This is much better
than a sodium iodide detector, which usually has a resolution of 5-10%. Moreover, the good resolution not only helps in separating closely spaced peaks, but it also helps in detecting weak sources of discrete energies when superimposed on a board continuum. Germanium detectors, however, are smaller in size and germanium has a lower atomic number than iodide. This means that the photopeak efficiencies will be lower than that of an inorganic scintillator (Knoll, 2000). Specifically for this study, it is much more important to be able to separate close peaks and also detect weak energies, than it is to have high photopeak efficiencies.

There are many isotopes created during weapons testing. Many of them are short-lived and will no longer be detected. Of the radioisotopes that are still left: $^3$H, $^{90}$Sr, $^{137}$Cs, $^{241}$Am, $^{235/238}$U, and $^{239/240}$Pu are of interest, due to their radioactivity (Qin-Hong, 2010). Of these, $^{137}$Cs, $^{241}$Am, and $^{235}$U will show up in gamma-ray spectroscopy.

1.3 Literature Review

1.3.1 The Nellis Dunes Recreational Area

Because air quality has become a major concern, especially in the southwest, Dr. Buck and Dr. Goossens aimed to measure the amount of dust produced from wind erosion and off-road vehicle driving at the NDRA. Several studies have found that being exposed to particulate matter (PM) can increase the risks of respiratory and cardiovascular diseases. The problem with most of these studies is they were set in urban areas, with little to no research of the health effects from inorganic mineral particles (Buck, Keli, Goossens, DeWitt, McLaurin, 2014). Dr. Buck, Dr. Goossens, and several other colleagues have now preformed several studies on the health effects of inorganic mineral particles and on the dust production produced by off road vehicles.
An important aspect to come from one of these studies was the 17 different surface units selected for this study. These surfaces were identified in the NDRA based on textural composition, surface crusts, rock cover, and vegetation. They were then grouped into four major classes: sand and sand-affected areas; silt and clay areas; rock-covered areas; and drainage areas (McLaurin et al. 2011). This was an important classification because it set the location for where dust samples could be collected for this study and future studies.

Another important part of these studies was the calculation of the total dust production in the NDRA from both natural and anthropogenic emissions (Goossens et al., 2012). This particular study resulted in finding that off-road vehicle activity can produce just as much dust emission as that created by wind erosion. Moreover, the results found that wind erosion is a dominant dust-producing mechanism in sand and sand-affected areas, but is poor when it comes to producing dust in areas rich in silt. This was the opposite for ORV driving, which produces a large amount of dust in silt areas, but is bad at producing dust in sand. Not only does ORV driving create as much dust as wind erosion, it does so in a different type of soil (Goossens et al., 2012).

1.3.2 Similar Studies

One study by I. Valles, looked at several naturally occurring and anthropogenic radionuclides in particulate matter in the Barcelona area during the period from January 2001 to December 2005. In this study, the authors took air filters collected from different locations and used HPGe detectors to determine the activities and type of radioisotope in the dust. The main idea behind this paper was to study the origin, annual course, and the effects of rain fallout on natural and anthropogenic radionuclides in the air near the surface. Of the conclusions made, the main discovery was that, in the majority of months, the average activities of $^{210}\text{Pb}$, $^{7}\text{Be}$, and $^{40}\text{K}$ measured in the air during dry weeks were higher than for rainy weeks due to the washout effect of rain, which lowered the
concentration of these radionuclides in airborne particulate material. Moreover, $^{137}$Cs was usually only detected during dry weeks. This showed that the presence of $^{137}$Cs was due to re-suspension of particles from the soil (Valles, 2009). This study helps to show that a drier climate will contain higher levels of radioisotopes than what would be normally seen.

Another similar study by F. Hernández took radiometric compositions of airborne particulate samples that were collected weekly for a 4 year period at a site located near Tenerife (Canaray Islands). Two different aerosol sample pumps were placed 100 meters apart to collect total suspended particulate matter. Dust content was collected in the filters and then were weighed by weighting the filters before and after the collection. Then gamma measurement was performed with two coaxial-type germanium detectors. They found that $^{137}$Cs had an average activity of $1.15 \times 10^{-6}$ Bq/m$^3$, $^{40}$K had an average activity of $2.5 \times 10^{-5}$ Bq/m$^3$, $^{212}$Pb had an average activity of $4.52 \times 10^{-5}$ Bq/m$^3$, and $^{214}$Pb had an average activity of $6.648 \times 10^{-6}$ Bq/m$^3$ (Hernandez, 2005). Even though these numbers come from a vastly different climate, they help to establish a rough baseline for comparison with the actives found at the recreational area.

Lastly, a study by B. Baggoura, took a look at a national environmental sampling program that was carried out during 1993. This program was done to figure out the natural and artificial radionuclides contents in the upper layers of the soil. The main purpose of this was to establish a radioactive reference level for the whole territory. Soil samples were carried out in the whole country covering a total area of 2,341,000 km$^2$. Due to the heterogeneity of the environment the country was divided into the three different zones. A northern zone, which is a small strip of land between the Mediterranean Sea and the Atlas Mountains, a central zone, which is located between the Atlas Mountains and the Sahara desert and finally a southern zone, which was a large desert area. Sampling was carried out in all the 48 administrative division of the country. A total number
of 219 samples were collected, mainly from coarse sands and were manually collected in undisturbed upper layer using the correct equipment. These samples were then put into high purity germanium detectors with and efficiency of 23%. A wide variety of activity concentrations are given for radionuclides such as $^{214}\text{Pb}$, $^{212}\text{Pb}$, $^{40}\text{K}$, and $^{137}\text{Cs}$ (Baggoura, 1998). These numbers will be a great comparison to the activities found at the recreational area. This will especially be for the $^{137}\text{Cs}$ concentrations which are pre Fukushima.

1.3.3 Fallout Mechanics

Other studies of importance are studies that specifically look at the distribution of radionuclides from nuclear testing. One such study by S. Simon, A. Bouville, and H. Beck was done to figure out the deposition of radionuclides produced from weapons tests done inside the United States and globally, with a main focus on the deposition of radionuclides from the Nevada Test Site. The radionuclides looked at were $^{131}\text{I}$ and $^{137}\text{Cs}$. Both $^{131}\text{I}$ and $^{137}\text{Cs}$ released from the Nevada Test Site had similar patterns of deposition and that the patterns of deposition showed that the highest amounts spread in the southeast direction over the corner of the state of Utah. As it happens the NDRA is southeast of the Nevada Test Site. The actives for $^{131}\text{I}$ ranged from 50 kBq m$^{-2}$ to about 1400 kBq m$^{-2}$ whereas for $^{137}\text{Cs}$ the activities ranged from 0.1 kBq m$^{-2}$ to 1 kBq m$^{-2}$ (Simon, Bouville, and Beck, 2002).

A very similar study to this is by H. Beck, and B. Bennett which focused on the fact that the local, intermediate, and global fallout deposition densities downwind from test sites depend on the heights of the bursts, the yields, the half-lives, the volatilities of a particular fission or activation product; and the meteorological conditions. For this study $^{137}\text{Cs}$, $^{90}\text{Sr}$, $^{93}\text{Zr-Nb}$, $^{131}\text{I}$, $^{140}\text{Ba-La}$, and $^{239/240}\text{Pu}$ were the nuclides looked at for their total deposition density from global fallout and the deposition from NTS. The study found that depositions at any given location varied as a function
of distance from the test sites by latitude, longitude, and local precipitation. The weapons testing conducted at the Nevada Test Site for instance, deposited most of its fallout in states downwind from itself. Where the highest measured deposition of $^{137}\text{Cs}$ in a populated area was about 5,500 Bq m$^{-2}$ found near the NTS. This is in contrast to global fallout, which was higher in wetter eastern sections of the country. The study goes on to state that even though fallout was generally dispersed around the world, the people who were living downwind close to the test sites may have gotten a fair amount of exposure (Beck and Bennett, 2002).

1.3.4 Dose estimates from Nuclear Weapons Testing

The main risk with nuclear testing is that it is never contained to the site. Though the explosion may be very far from any inhabitant fallout will end up coating the area downwind of the tests and giving both an external and internal exposure to the population. Bouville, and André summarizes information about external and internal doses from not only global fallout but also doses from intermediate fallout in the United States. Though most of the global fallout effective does came from other reports, separate calculations were made for the tests conducted at the Nevada Test site. It was found that the estimated average does from external irradiation from the Nevada Test was around 0.5 mGy whereas the average doses from internal irradiation vary quite a bit from one organ or tissue to another. For instance, the internal dose for red bone marrow from $^{137}\text{Cs}$ was around 0.009 mGy while the internal dose for red bone marrow from $^{90}\text{Sr}$ was around 0.02 mGy. These doses were calculated by first considering two pathways: external irradiation from actives deposited on the ground and internal irradiation from the ingestion of contaminated foodstuffs. The doses from external irradiation were estimated using assumptions and parameters values similar to those used by UNSCEAR (2000). To calculate dose estimated from internal irradiation, a method was created by the Off-Site Radiation Exposure Review Project (ORERP). They as well
used a method similar to UNSCEAR (2000) but made their method more complex because the process involved in the estimation of radionuclides concentrations in foodstuffs and the intakes by humans were studied in more detail. The ORERP method included estimating the total amount of an individual radionuclide that might be ingested by humans of differing ages, as well as, estimating the dose at each age that a member of the public would receive from ingesting a single unit of activity of a particular radionuclide. (Bouville, 2002).

Another study that looked at internal doses from fallout was performed by Robert Weinstock. This study calculated annual internal radiation doses resulting from both acute and chronic intakes of all important does-contributing radionuclides that occur in fallout from nuclear weapons testing. Namely at Bikini and Enewtak from 1946 through 1958. The doses were estimated for residents living on all atolls and separate reef island of the Marshall Islands. Internal doses were determined for all tissues most at risk of cancer, red bone marrow, thyroid, stomach, and colon, have been estimated for people of all the population communities from birth years from 1929 to 1968, and for all years of exposure from 1948 through 1970. The model they used for the chronic intake estimated was based on reported whole body, urine and blood counting data for residents of Utrik and Rongelap. Dose conversion coefficients for intake to organ absorbed dose were developed using internationally accepted models, ICRP Publication 72; 1996, and then specifically tailored for intakes of particulate fallout. It was found that the two most important radionuclides giving the highest cumulative organ does to adults from chronic intakes of long-lived radionuclides were $^{65}$Zn and $^{137}$Cs. With the highest dose being 89 mGy to the thyroid for $^{65}$Zn and 8.8 mGy to the colon for $^{137}$Cs (Wininstock, 2010).
1.3.5 Dose estimate from Naturally occurring Radionuclides

The best evaluation of dose estimated from naturally occurring radionuclides comes from NCRP Report No. 94. This report was created to give a summary of several reports on exposures to natural radiation. The report not only looks at terrestrial radioactive, but also exposures from extra-terrestrial source. Both of these sources have external and internal components to them and that is also taken into consideration. In the report there are several tables that go over the deposited amount of radioactive material and the doses that correspond to them. For instance, the inhalation of $^{40}$K amounts to an average of 130 uSv/y in the soft tissue, where $^{212}$Pb has a dose equivalent rate of 0.1 uSv/y in the whole lung. These numbers will help relate the amount someone could potentially get out at the recreational area (NCRP Report No. 94).

1.3.6 Lung Dose Model

ICRP 66 is used to create lung dose models for a repository uptake. The lung dose model works by breaking the lung into five different regions. These five different regions are then divided up into even smaller parts.
This is done to calculate how much of a radionuclide gets deposited in each of these regions. Once that has been determined, then dose calculations are performed for each of these regions and then they are added to each other to get a total dose for the lung.

Before being able to figure out how much a radionuclide gets deposited in each region of the lung, the total amount of dust being inhaled must be calculated. To figure that out the aerodynamic diameter of the dust particles has to be calculated out by using equation D.5 from ICRP 66 Appendix D:

**Equation 1. Aerodynamic Diameter**

\[ d_{ae} = d_e \left[ p \cdot C(d_e)/\rho_0 \cdot C(d_{ae}) \right]^{1/2} \]

Where \( d_e \) is the volume diameter, \( x \) is the shape factor, \( p \) is the mass density, \( \rho_0 \) is the unity density (1 g/cm³), and \( C(d_e) \) and \( C(d_{ae}) \) are the slip correction factor. Which is calculated by:
Equation 2. Slip correction Factor

\[ C(d_e) = 1 + (\lambda/d_e)^*\{2.514 + .8\exp[-.55(d_e/\lambda)]\} \]

Once the aerodynamic diameter is obtained the regional deposition can but found by using figure 10 from chapter 5 of ICRP 66.

Figure 8. Figure 10 from Chapter 5 of ICRP 66. Fractional depositions in each region of the respiratory tract. Retrieved from ICRP 66

After obtaining the regional deposition the next step is to calculate the factor for partitioning regional deposits among the regional compartments.
Table 2. Factor for partition regional deposits amount the Regional Compartments using information from ICRP 66

<table>
<thead>
<tr>
<th>Region</th>
<th>Compartment</th>
<th>Fraction to Compartment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET1</td>
<td>ET1</td>
<td>1</td>
</tr>
<tr>
<td>ET2</td>
<td>ET2</td>
<td>0.9995</td>
</tr>
<tr>
<td></td>
<td>Etseq</td>
<td>0.005</td>
</tr>
<tr>
<td>BB</td>
<td>BB1</td>
<td>0.993-fs</td>
</tr>
<tr>
<td></td>
<td>BB2</td>
<td>fs</td>
</tr>
<tr>
<td></td>
<td>Bbseq</td>
<td>0.007</td>
</tr>
<tr>
<td>bb</td>
<td>bb1</td>
<td>0.093-fs</td>
</tr>
<tr>
<td></td>
<td>bb2</td>
<td>fs</td>
</tr>
</tbody>
</table>

Where:

Equation 3. Size-dependent parameter

\[ fs = 0.5 \exp\left[-0.63(dx_p^{1/2}+2.5)\right] \]

Table 2 is used to calculate how much activity goes to each different region. The next step is to calculate how long the dust stays in each compartment. Equation 8.31 from Cember is used for that:

Equation 4. Mean Resident Time

\[ MRT = \frac{1}{\lambda_E} \]

Where:
Equation 5. Effective clearance rate

\[ \lambda_E = \lambda_{ab} + S_s + \lambda_r \]

Values for \( \lambda_{ab} \) were taken from Table 8-16 in Cember, values for \( S_s \) were obtained from Table 8-13 in Cember, and \( \lambda_r \) is the decay constant. Once this data has been calculated, the total number of disintegrations in each compartment must be solved by using equation 8.32 from Cember:

\[ N_{ci} = A_{ci \, dis/s} \times 8.64 \times 10^4 \, s/d \times MRT \]

With the total number of disintegration in each compartment calculated, the regional dose is figured out by using equation 8.37 from Cember:

Equation 7. Regional dose

\[ H(\text{region}) = [\Sigma (E \, MeV/\text{dis} \times 1.36 \times 10^{-13} \, J/\text{MeV} \times Y \times w_T \times w_R \, Sv/Gy) / (m \, kg \, 8 \, I/kg/Gy)] \]

\[ \times \Sigma N_{ci \, dis} \times AF(T < S) \]

Where \( E \) is the energies of radiation given off (Table Isotopes Decay Data), \( Y \) is the yield of that radiation (Table Isotopes Decay Data), \( w_T \) is the tissue weighting factor (Table 8-14 Cember), \( w_R \) is the radiation weighing factor, and \( AF(T < S) \) is the fraction of energy emitted from the source to the target tissue (Taken from Tables in Appendix H and Appendix G from ICRP 66.) This equation
yields the dose to region of the lung. Then each region of the lung can be added together to get the equivalent dose to the lung.

### 1.4 Research Goals

Preliminary studies have shown a difference in activities of the same radionuclide not only for different soil types but also for different particles sizes. This discovery warranted a deeper look at this phenomenon. Moreover, the dust samples were collected in an area where a large group of people are kicking up a fair amount of dust and their safety, not only for inhaling that dust, but also because what is potentially attached to that dust is of importance. The purpose of this study is to determine the amounts of naturally occurring and man-made radionuclides present in very small amounts of dust and soil collected from the Nellis Dunes Recreational Area (NDRA) to determine if it is possible to establish correlations between radioisotopes and particle size as well as different soil types. The radionuclides in question that will most likely be seen are: the daughters of the thorium decay series, the daughter from the two uranium decay series, potassium forty, cesium 137, and americium 231. Finally, once all the data has been collected a lung dose model will be created to assess the dose and potential risk of anyone who is inhaling this dust. The Nellis Dunes Recreational Area was selected for collecting samples for several reasons. First, it is within 500 km of the Nevada National Security Site. This is important because not only will long lived radionuclides from global fallout be present, but long lived radionuclides from local fallout can be found as well. Second, the samples were already collected and being used for other studies. Third, the NDRA has become a popular place for human activity, this means that people have the potential to be at risk from radiation exposure and steps need to be taken to assess how much danger they are in.
CHAPTER 2. MATERIALS AND METHODOLOGY

2.1 Materials

- 18 5 mL scintillation vial filled with 1 gram of dust each
- 1 Canberra Model GR3519 high-purity germanium gamma well detector with a relative efficiency of 35%
- Canberra’s Genie 2000 software
- 1 Certified soil reference standard containing sieved Griffin soil in a 5 mL liquid scintillation vial (Eckert & Ziegler Analytics Serial # 92653)

2.2 Sample Collection

Samples were collected by Dr. Buck and her associates. Samples were prepared by first collecting the upper 2 centimeters of topsoil with a plastic scoop. The soil was then put in a clean plastic bag and hermetically sealed. Afterwards, soil samples were air dried at the laboratory. All lose sediment was then sieved using a plastic sieve with a 2 millimeters mesh sizes to remove the coarse fragments. Again, additional sieving was preformed to obtain particle size fractions of: 2000-1000 micrometers in diameter, 1000-500 micrometers in diameter, 500-250 micrometers in diameter, 250-125 micrometers in diameter, 125-60 micrometers in diameter, and 60 micrometer or less in diameter. Once the additional sieving was done, one gram of soil was taken from each sample and placed into a five milliliter scintillation vial (See Figure 10). Even though several location of interest were sampled, for this experiment dust and soil from only three locations were used (See Figure 9).
Figure 9. Location of the three dust sampling sites. DS11 is red, DS15 is purple, and DS26 is black. Retrieved from McLaurin et al., 2011.

Dust sample 11 comes from map unit 2.4 disturbed silt surfaces. This soil is a mixture of noncrusted silt and rock fragments over bedrock. This type of area occurs where the surfaces has been disturbed by human activity. Map unite 2.4 is made up of roughly 42.3% gravel, 54.8% sand, 3.9% silt and clay, and has a median grain diameter of 193 μm. Dust sample 15 comes from map
unit 2.2 silt and clay with gravel. This map unit is a mixture of silt and gravel, but with more silt, >85% in weight, than gravel on the surfaces. These map units are typically found on hill slopes and plateau escarpments. Map unit 2.2 is made up of roughly 24.5% gravel, 61.2% silt, 11% and clay, and has a median grain diameter of 52 um. Lastly, dust sample 26 comes from map unit 1.4 which is patchy layers of sand over silty or rocky subsoil. This map unit is a thin layer of sand, roughly 1-3 cm, covering the subsoil. Several underlying clasts are exposed at the surfaces. The sand here is active and small dunes can occur. This map unit is made up of 40.8% gravel, 57.3% sand, 1.4% silt and clay, and has a median grain diameter of 153 um (McLaurin et al, 2011).

![Figure 10. Dust samples contained in 5 mL liquid scintillation vials.](image)

### 2.3 Gamma Spectroscopy

A Canberra Model GR3519 high-purity germanium gamma well detector (Figure 11) was used to determine the activity of the radionuclides present in each sample. This particular model has a relative efficiency of 35% and was operated using Canberra’s Genie 2000 software. A certified soil reference standard, purchased from Eckert & Ziegler analytics, consisting of sieved griffin soil spiked with known amounts of nine radionuclides in a 5 mL liquid scintillation vial was used for energy and efficiency calibrations. The standard radionuclide source was previously prepared by the vendor using aliquots measured gravimetrically from master radionuclide solutions. Additional radionuclides were added gravimetrically from solutions calibrated by gamma-ray spectrometry,
ionization chamber, or liquid scintillation counting. At the time of calibration no interfering gamma-ray emitting impurities were detected.

Table 3. Nuclides in Eckert & Ziegler Analytics calibration standard

<table>
<thead>
<tr>
<th>Eckert &amp; Ziegler Analytics Sample</th>
<th>Nuclide</th>
<th>Energy (keV)</th>
<th>γps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Am-241</td>
<td>59.5</td>
<td>65.39</td>
<td></td>
</tr>
<tr>
<td>Cd-109</td>
<td>88</td>
<td>93.31</td>
<td></td>
</tr>
<tr>
<td>Co-57</td>
<td>112.1</td>
<td>50.56</td>
<td></td>
</tr>
<tr>
<td>Ce-139</td>
<td>165.9</td>
<td>70.75</td>
<td></td>
</tr>
<tr>
<td>Hg-203</td>
<td>279.2</td>
<td>143.6</td>
<td></td>
</tr>
<tr>
<td>Sn-113</td>
<td>391.7</td>
<td>98.55</td>
<td></td>
</tr>
<tr>
<td>Cs-137</td>
<td>661.7</td>
<td>65.43</td>
<td></td>
</tr>
<tr>
<td>Y-88</td>
<td>898</td>
<td>241.1</td>
<td></td>
</tr>
<tr>
<td>Y-88</td>
<td>1836.1</td>
<td>255.2</td>
<td></td>
</tr>
<tr>
<td>Co-60</td>
<td>1173.2</td>
<td>121.6</td>
<td></td>
</tr>
<tr>
<td>Co-60</td>
<td>1332.5</td>
<td>121.6</td>
<td></td>
</tr>
</tbody>
</table>

Figure 11. Canberra Model GR3519 high-purity germanium gamma detector used to measure samples (left side)

2.4 Sample Counting

First, an energy calibration was performed using the certified standard soil reference from Eckert and Ziegler (See Figure 14). Eleven gamma lines were used for this energy calibration and it was repeated every six months. Then a background was measured for 168 hours of live time (See Figure 15). Almost no dead time was noted. Then the samples were also each counted for a lifetime of 168 hours. The data was subsequently analyzed using Canberra’s Genie 2000 software.
To analyze each sample several steps were taken. First, the presence of the appropriate energy and efficiency calibrations was confirmed for every sample. The energy calibration was done by fitting a linear function to the data and having a full width half maximum calculation as well as a low tail calculation preformed (See Figure 12). A dual function type was used for the efficiency calibration (See Figure 13). Then each peak was located on the spectrum. Once a peak locate was done, a visual inspection was carried out to make sure each noticeable peak was located and that several of the peaks were at the correct energy for a given nuclide. After that each peak’s area was recorded. The next step was to subtract the background from the spectrum. Then an efficiency correction was performed. Finally, the isotope library “STDLIB.NLB” was used to identify each nuclide and then manually checked to make sure that several of the peaks lined up with the correct energies. This library came pre-installed on the Canberra’s Genie 2000 software.

Figure 12. Plot of the energy calibration used for samples.
Figure 13. Plot of the efficiency calibration used for samples.

Figure 14. Calibration Spectrum of the Calibration Standard with labeled peaks.
Figure 15. Background Gamma spectrum
CHAPTER 3. RESULTS

Figure 16. Gamma spectrum with labeled peaks for Dust Sample 11, PM 60

Table 4. Activities for dust sample 11, disturbed silt surfaces in micro curies per gram

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>2000-1000</th>
<th>Unc.</th>
<th>1000-500</th>
<th>Unc.</th>
<th>500-250</th>
<th>Unc.</th>
<th>250-125</th>
<th>Unc.</th>
<th>125-60</th>
<th>Unc.</th>
<th>60</th>
<th>Unc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{214}$Pb</td>
<td>1.65E-06</td>
<td>7.76E-08</td>
<td>2.73E-06</td>
<td>1.04E-07</td>
<td>1.58E-06</td>
<td>7.98E-08</td>
<td>1.37E-06</td>
<td>7.57E-08</td>
<td>2.44E-06</td>
<td>1.02E-07</td>
<td>3.11E-06</td>
<td>1.18E-07</td>
</tr>
<tr>
<td>$^{213}$Th</td>
<td>BDMA*</td>
<td>N/A</td>
<td>BDMA</td>
<td>N/A</td>
<td>BDMA</td>
<td>N/A</td>
<td>2.95E-07</td>
<td>1.03E-07</td>
<td>6.36E-07</td>
<td>1.08E-07</td>
<td>5.74E-07</td>
<td>1.06E-07</td>
</tr>
<tr>
<td>$^{212}$Pb</td>
<td>2.22E-07</td>
<td>5.65E-08</td>
<td>5.22E-07</td>
<td>1.04E-07</td>
<td>6.83E-07</td>
<td>6.10E-08</td>
<td>5.74E-07</td>
<td>6.05E-08</td>
<td>1.03E-06</td>
<td>8.68E-08</td>
<td>1.34E-06</td>
<td>9.68E-08</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>BDMA</td>
<td>N/A</td>
<td>BDMA</td>
<td>N/A</td>
<td>BDMA</td>
<td>N/A</td>
<td>BDMA</td>
<td>N/A</td>
<td>BDMA</td>
<td>N/A</td>
<td>N/A</td>
<td>1.59E-07</td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>1.11E-05</td>
<td>1.37E-06</td>
<td>1.75E-05</td>
<td>1.47E-06</td>
<td>3.62E-05</td>
<td>1.89E-06</td>
<td>3.66E-05</td>
<td>1.90E-06</td>
<td>3.86E-05</td>
<td>1.95E-06</td>
<td>3.74E-05</td>
<td>1.92E-06</td>
</tr>
</tbody>
</table>

Table 5. Activities for dust sample 15, silt and clay with gravel in micro curies per gram

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>2000-1000</th>
<th>Unc.</th>
<th>1000-500</th>
<th>Unc.</th>
<th>500-250</th>
<th>Unc.</th>
<th>250-125</th>
<th>Unc.</th>
<th>125-60</th>
<th>Unc.</th>
<th>60</th>
<th>Unc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{214}$Pb</td>
<td>4.32E-07</td>
<td>1.03E-07</td>
<td>5.60E-07</td>
<td>1.05E-07</td>
<td>5.60E-07</td>
<td>1.08E-07</td>
<td>4.33E-07</td>
<td>8.80E-08</td>
<td>6.11E-07</td>
<td>9.06E-08</td>
<td>7.70E-07</td>
<td>9.46E-08</td>
</tr>
<tr>
<td>$^{212}$Pb</td>
<td>1.99E-06</td>
<td>2.57E-06</td>
<td>9.56E-08</td>
<td>2.63E-06</td>
<td>9.92E-08</td>
<td>1.76E-06</td>
<td>5.47E-08</td>
<td>1.88E-08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>1.09E-05</td>
<td>1.35E-06</td>
<td>1.61E-05</td>
<td>1.45E-06</td>
<td>1.31E-05</td>
<td>1.40E-06</td>
<td>1.72E-05</td>
<td>1.23E-06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Activities for dust sample 26, patchy layers of sand over silt in micro curies per gram

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>2000-1000</th>
<th>Unc.</th>
<th>1000-500</th>
<th>Unc.</th>
<th>500-250</th>
<th>Unc.</th>
<th>250-125</th>
<th>Unc.</th>
<th>125-60</th>
<th>Unc.</th>
<th>60</th>
<th>Unc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{214}$Pb</td>
<td>8.36E-07</td>
<td>4.16E-08</td>
<td>1.02E-06</td>
<td>4.38E-08</td>
<td>8.64E-07</td>
<td>4.20E-08</td>
<td>5.36E-07</td>
<td>3.81E-08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{213}$Th</td>
<td>2.94E-07</td>
<td>3.37E-08</td>
<td>4.42E-07</td>
<td>3.51E-08</td>
<td>4.82E-07</td>
<td>3.61E-08</td>
<td>2.99E-07</td>
<td>3.27E-08</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>7.41E-08</td>
<td>1.38E-08</td>
<td>9.47E-08</td>
<td>1.59E-08</td>
<td>1.44E-07</td>
<td>1.68E-08</td>
<td>7.32E-08</td>
<td>1.44E-08</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>$^{40}$K</td>
<td>1.09E-05</td>
<td>1.31E-06</td>
<td>7.38E-06</td>
<td>1.09E-06</td>
<td>1.79E-06</td>
<td>1.24E-06</td>
<td>2.22E-05</td>
<td>1.32E-06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* BMDA: Below Minimum Detectable Activity.
Table 7. Activities for soil samples in micro curies per gram

<table>
<thead>
<tr>
<th>Soil Samples</th>
<th>15</th>
<th>26</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{214}$Pb</td>
<td>9.82E-05</td>
<td>3.14E-05</td>
</tr>
<tr>
<td>$^{214}$Bi</td>
<td>1.17E-04</td>
<td>3.97E-05</td>
</tr>
<tr>
<td>$^{235}$U</td>
<td>5.31E-06</td>
<td>6.27E-06</td>
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<tr>
<td>$^{231}$Th</td>
<td>3.05E-05</td>
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</tr>
<tr>
<td>$^{212}$Pb</td>
<td>4.11E-05</td>
<td>3.78E-05</td>
</tr>
<tr>
<td>$^{212}$Bi</td>
<td>3.61E-05</td>
<td>2.18E-05</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>5.79E-07</td>
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</tr>
<tr>
<td>$^{40}$K</td>
<td>1.55E-03</td>
<td>1.24E-03</td>
</tr>
</tbody>
</table>
CHAPTER 4. LUNG DOSE MODEL

4.1 Model Design

The lung dose model was created based on information from ICRP 66 (ICRP 66, 1994). The first step in creating a lung dose model was to create a person who would be inhaling this dust. This was done by utilizing the reference man used by the Nuclear Regulatory Commission that can be found in ICRP 23 (ICRP 23, 1975). By using the reference man the weights of different tissues and organs needed for the model are already given. The next step was to give the reference man a reason to be out on the dunes. This person would be a hypothetical off-road driving instructor, meaning he would spend an 8 hour work-day at this location with a breathing rate of 1.5 m$^3$ for light labor.

Another set of assumptions needed was the exact composition of the dust sample. Th-231, Pb-212, and Pb-214 all have such short half-life’s, that unless a parent nuclide was also present in the sample, they would not still appear by the time the sample was counted. Therefore, it had to be assumed that they were originating from the decay of parent nuclides that did not register during the gamma counting. So not only would these three isotopes be present, but they would be in secular equilibrium with a parent nuclide with a sufficiently long half-life. For $^{231}$Th its parent nuclide would be $^{235}$U, the parent for $^{212}$Pb nuclide would be $^{226}$Ra and all of its daughters, and for $^{214}$Pb the parent nuclide that would still be in the sample would be $^{228}$Th and all of its daughters. It should also be noted that for both $^{212}$Pb and $^{214}$Pb, radon gas would be a member of the respective decay chain. To handle this issue two separate lung dose models were prepared. The first one would assume that the radon gas would be created in a solid matrix and not leave the dust particle, thereby adding itself and any daughters to the dose. The second one assumed the radon gas left the lungs and would not be added to the dose.
The first step was calculating exactly how much activity was taken up into the lung. The activity concentration for each isotope in the dust samples was given in micro curies per gram. For the lung dose model they were all converted into Becquerel. This was done by first converting the data into units of Becquerel per gram, which is done with a simple conversion. After that, the data needed to be converted into Becquerel per meter cubed. This was accomplished by multiplying the current data by the average concentration of dust in the air, which is given in milligrams per meter cubed. The concentration for dust in the air was calculated with data obtained from an experiment described in the NDRA Dust Exposure and Health Risk Assessment report (Buck et al., 2014). In this experiment it was concluded that drivers were exposed to dust concentrations ranging from 4.5 to 37.3 mg/m$^3$. Because there is such a wide range of dust exposures, the lung dose model was split again and one model would assume that the driver was exposed to 4.5 mg/m$^3$ while the other model would assume the drivers were exposed to 37.3 mg/m$^3$. It should be noted in this experiment that riders were asked to follow in a line, driving around 10mph with a distance of 10 to 15 meters apart. Furthermore, the trail they were asked to ride on was composed of all the soil types (Buck et al., 2014). Though these are not quite the exact condition a hypothetical instructor would encounter, these are the closest realistic numbers seeing as the measurements were performed at the driver’s nose and mouth. Using these numbers, the data was converted into units of Becquerel per meter cubed. The final part of this step was to then convert the data into total activity in units of Becquerel. This was done by using equation nine from ICRP 66 Chapter four, \( I_0 = C_A t B \), where \( C_A \) is the concentration of activity in air (in Bq/m$^3$), \( t \) is the exposure duration (in hours), which stated previously was 8 hours, and \( B \) is the breathing rate (in m$^3$ h$^{-1}$) which for light exercise is 1.5 m$^3$/h (ICRP 66, 1994).
After calculating the total activity inhaled per day, the next step was to calculate the aerodynamic diameter. This was carried out using equation 1. With the aerodynamic diameter known, the regional deposition was found by using figure 10 from chapter 5 of ICRP 66 (ICRP 66, 1994). The next step was to calculate the factor for partitioning regional deposits among the regional compartments by using equation 3 and table 2. The calculation of how long the dust stayed in each region was performed by applying equation 4 which gives the mean residence time or MRT. With the MRT known, equation 6 was used to calculate the total number of disintegration in any compartment.

Once the total number of disintegration in each compartment had been determined, equation 7 was used to calculate the regional dose. This equation yielded the results for the dose for each region which were then added together to get the equivalent dose per isotope. Moreover, the amount of activity taken out by absorption into the blood and amount of activity taken into the gastrointestinal tract was recorded for later use. The equivalent dose per isotope was integrated for 70 years, the amount of time recommended to integrate by the NRC for the general public, to get the committed effective dose per isotope. At the same time dose coefficients from: ICRP 71, ICRP 119, and two studies by G. Kendall and T. Smith were used to get the committed effective doses’ for each isotope for the activities that were transferred to the blood and to the gastrointestinal tract. Then the committed effective doses per isotope for the lungs, bone surfaces, and gastrointestinal tract, were multiplied by the respective tissue weighting factors and added together to get a committed effective dose equivalent, CEDE, for each isotope for one day of inhaling dust. Afterwards, each isotope’s CEDE was added to the other isotope’s CEDEs in each sample to get a CEDE for a day of breathing out at the dunes. Finally, the CEDE for each sample was multiplied by 250 days, roughly how many working days an American has, to get a yearly CEDE for breathing
in each sample. Also, it should be noted that when comparing this model to the example given in ICRP 66 the results were only off by 3.36% from ICRP 66’s example. Moreover, the results were only off by 2.43% from the example given in Cember (Cember, 2009). When comparing the model presented in this thesis against ICRP’s Dose-Coefficients, Cs-137 was off by 3.7% and K-40 showed a difference off by 2.4%. These comparisons were carried out to ensure the model’s accuracy and to show that the model used in this work is within 95% confidence compared with other working lung models.

4.2 Results of Lung Dose Model

Table 8. Committed Effective Dose Equivalent for all Samples, with radon included, high dust yield

<table>
<thead>
<tr>
<th>Dust Sample</th>
<th>CEDE for one Day (Sv)</th>
<th>CEDE for one year (Sv)</th>
<th>CEDE for one year (rem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust Sample 11, PM 60</td>
<td>3.01E-06</td>
<td>6.01E-04</td>
<td>6.01E-02</td>
</tr>
<tr>
<td>Dust Sample 11, PM 10</td>
<td>3.42E-06</td>
<td>6.84E-04</td>
<td>6.84E-02</td>
</tr>
<tr>
<td>Dust Sample 15, PM 60</td>
<td>2.81E-06</td>
<td>5.61E-04</td>
<td>5.61E-02</td>
</tr>
<tr>
<td>Dust Sample 15, PM 10</td>
<td>3.20E-06</td>
<td>6.41E-04</td>
<td>6.41E-02</td>
</tr>
<tr>
<td>Dust Sample 26, PM 60</td>
<td>2.81E-06</td>
<td>5.61E-04</td>
<td>5.61E-02</td>
</tr>
<tr>
<td>Dust Sample 26, PM 10</td>
<td>3.21E-06</td>
<td>6.43E-04</td>
<td>6.43E-02</td>
</tr>
</tbody>
</table>
Table 9. Committed Effective Dose Equivalent for all Samples, without radon, high dust yield.

<table>
<thead>
<tr>
<th>Dust Sample</th>
<th>CEDE for one Day (Sv)</th>
<th>CEDE for one year (Sv)</th>
<th>CEDE for one year (rem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust Sample 11, PM 60</td>
<td>2.04E-06</td>
<td>4.08E-04</td>
<td>4.08E-02</td>
</tr>
<tr>
<td>Dust Sample 11, PM 10</td>
<td>2.35E-06</td>
<td>4.70E-04</td>
<td>4.70E-02</td>
</tr>
<tr>
<td>Dust Sample 15, PM 60</td>
<td>1.77E-06</td>
<td>3.55E-04</td>
<td>3.55E-02</td>
</tr>
<tr>
<td>Dust Sample 15, PM 10</td>
<td>2.06E-06</td>
<td>4.11E-04</td>
<td>4.11E-02</td>
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<tr>
<td>Dust Sample 26, PM 60</td>
<td>1.94E-06</td>
<td>3.87E-04</td>
<td>3.87E-02</td>
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<tr>
<td>Dust Sample 26, PM 10</td>
<td>2.24E-06</td>
<td>4.49E-04</td>
<td>4.49E-02</td>
</tr>
</tbody>
</table>

Table 10. Committed Effective Dose Equivalent for all Samples, with radon included, low dust yield.

<table>
<thead>
<tr>
<th>Dust Sample</th>
<th>CEDE for one Day (Sv)</th>
<th>CEDE for one year (Sv)</th>
<th>CEDE for one year (rem)</th>
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</thead>
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<tr>
<td>Dust Sample 11, PM 60</td>
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<td>3.86E-07</td>
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<td>7.73E-03</td>
</tr>
<tr>
<td>Dust Sample 26, PM 60</td>
<td>3.39E-07</td>
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<td>6.77E-03</td>
</tr>
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<td>Dust Sample 26, PM 10</td>
<td>3.88E-07</td>
<td>7.75E-05</td>
<td>7.75E-03</td>
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</table>
Table 11. Committed Effective Dose Equivalent for all Samples, without radon, low dust yield

<table>
<thead>
<tr>
<th>Dust Sample</th>
<th>CEDE for one Day (Sv)</th>
<th>CEDE for one year (Sv)</th>
<th>CEDE for one year (rem)</th>
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<tr>
<td>Dust Sample 11, PM</td>
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<td>7.55E-04</td>
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<td>60</td>
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<td>Dust Sample 11, PM</td>
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<td>9.98E-06</td>
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<tr>
<td>Dust Sample 15, PM</td>
<td>3.56E-08</td>
<td>7.13E-06</td>
<td>7.13E-04</td>
</tr>
<tr>
<td>60</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Dust Sample 15, PM</td>
<td>4.70E-08</td>
<td>9.40E-06</td>
<td>9.40E-04</td>
</tr>
<tr>
<td>10</td>
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<td></td>
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</tr>
<tr>
<td>Dust Sample 26, PM</td>
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<td>8.65E-06</td>
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<td>60</td>
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</tr>
<tr>
<td>Dust Sample 26, PM</td>
<td>5.75E-08</td>
<td>1.15E-05</td>
<td>1.15E-03</td>
</tr>
<tr>
<td>10</td>
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</tbody>
</table>
5.1 Particle Size and Radionuclide

There are several notable points to bring up when it comes to the relationship between radionuclides and particle size. First, is the correlation $^{137}\text{Cs}$ has with particle size. In the dust samples taken at site 11 and 15, the only time $^{137}\text{Cs}$ can be found in size fractions with a diameter of 60 micrometers or less. On the other hand, $^{137}\text{Cs}$ showed up in every size fraction at site 26 except for dust that was 125-60 micrometers in diameter.

Figure 17. Activities of $^{137}\text{Cs}$ from all samples

A study by F. Livens took a look at particle size and radionuclide levels in west Cumbrian soils and observed that particle size did have an effect on activity levels. This change was as noticeable as a 3 to 35 time’s enhancement from larger particle sizes to smaller. For instance, when looking at sandy soil $^{137}\text{Cs}$ had an activity of 1580 Bq/kg for particles between 250-2000 μm where for
particles smaller than 2 μm the activity was 51400 Bq/kg (Livens, 1988). This behavior is noticed in the NDRA samples as well with the activity of $^{137}$Cs in sandy soil being 2.7417 Bq/kg for particles between 2000-1000 μm and 15.614 Bq/kg for particles less than 60 μm. Though this is not 35 times more, it is an increase by a factor of 5.7, which is a noticeable change. The reason behind this is that there is a cation/anion attraction between cesium and clay (L. Bergaoui, J.F. Lamber, R. Prost, 2004). Because clay is a finer particle, <2 um in diameter, it makes sense that a larger activity would be seen in the smaller particles, seeing as that is where the clay would have been sieved too. Cesium specifically has such a large change in sand samples because there is such a small amount of clay in sand samples that most of the radionuclide binding sites have to be provided by a fairly small amount of clay in comparison to other samples. This causes the clay in sand samples to have a fairly high specific activity (Livens, 1988).

Furthermore, this explains why $^{137}$Cs is seen in larger particles sizes in the sand sample but not in the clay or silt samples. Because there is so little clay in the sand sample all the binding sites are filled and the rest of the cesium will then bind to other, larger, particles in the sample. This is not the case in the clay or silt samples, which have a much higher concentration of clay in them. Because of this larger quantity of clay there are enough binding sites for the cesium where they do not have to bind to any other particle.

Second, there is a noticeable change in activity concentration between particle sizes for the other isotopes seen. Though no true pattern is seen, it appears that for the most part as particle size goes down, activity goes up. This is most noticeable for $^{212}$Pb, $^{231}$Th, and $^{40}$K, where for every site sampled the activity appear to increase as the particle size decreases. The other radionuclides found also tend to have a higher activity the smaller the dust particle is, however the fluctuations seen for this nuclides are much stronger.
Figure 18. Activities of $^{214}$Pb from all samples

Figure 19. Activities of $^{231}$Th from all samples
Figure 20. Activities of $^{210}$Pb from all samples

Figure 21. Activities of $^{40}$K from all samples
Potassium is chemically similar to cesium and has the same cation/anion attraction to clay as described previously (B.L. Shawhney, 1969). This makes it possible for potassium to also concentrate on the smaller particles samples. However, because there is significantly more $^{40}$K than $^{137}$Cs present in the samples, it does make sense that it is more spread out in the rest of the particle sizes than $^{137}$Cs is. Thorium and lead are also cations due to the fact that they are metals and will have an attraction to clay as well. This could provide a possible explanation for why they are also more heavily concentrated on the smaller particles.

5.2. Soil Type and Radionuclide

Soil type also played a factor in determining the degree to which a radionuclide attaches itself to dust. This is especially noticeable for $^{137}$Cs, where dust sample site 11 and dust sample site 15 have similar activities but dust sample site 26 has a noticeably higher activity. This is also fairly unusual seeing as dust sample site 26 has the lowest amount of clay content and therefore should have the lowest amount of $^{137}$Cs in total. When this oddity was discussed with Dr. Buck, two prevailing theories were put forward. The first theory for this oddity is that dust sample site 15 and 11 have been eroded, and thus the cesium that landed there has been re-suspended and blown down wind to land somewhere else, whereas dust sample site 26 has not been eroded. Dust site 26 is one of the most intact, non-eroded areas, and it is likely that the trapped fine-grained sediment contains the cesium. The other theory is that the coarser grains of sand are coated with clay, which is holding the cesium on exchange sites. There currently is no data available to support this idea, but clay and iron-oxide coated sand grains are very common features to the area, so this could be a possible cause.

The other nuclides found in the samples are all naturally occurring and their quantities would be based on the composition of the original minerals that the dust developed from. For instance,
$^{231}\text{Th}$ comes from the decay of $^{235}\text{U}$ and .73% of all naturally occurring uranium is $^{235}\text{U}$. Therefore, the samples that have the highest concentration of uranium in them would have the highest concentration of $^{231}\text{Th}$. When looking at Buck et al. 2014, the sample that has the highest uranium content out of the samples tested was soil type 2.2, or dust sample 15. This sample shows the most $^{231}\text{Th}$ in the current study. This is also true for $^{214}\text{Pb}$ which is part of $^{238}\text{U}$ decay series. So the sample with the highest uranium content should have the most $^{214}\text{Pb}$, which in the case dust sample 15.

### 5.3 Manmade Radionuclides

When looking over the data is clear that four out of the five radionuclides found are naturally occurring and only one is manmade. Cs-137 is the only manmade gamma-emitting radionuclide to be detected in any of the dust samples. Every year the Nevada National Security Site releases an annual report and during 2014 $^{137}\text{Cs}$ was detected at levels slightly above their MDCs in only three sampling areas around the site. Furthermore, it should be noted that these three samples were far below the concentration level mandated for environmental compliance. The activities found in these three samples were: $3.49 \times 10^{-17}$ uCi/ml, $8.93 \times 10^{-17}$ uCi/ml, and $10.08 \times 10^{-17}$ uCi/ml. Moreover, the Community Environmental Monitoring program, a network of monitoring stations located in communities surrounding and downwind of the Nevada National Security Site, that monitors the air for manmade radioactivity that could result from the NNSS activities, has found no $^{137}\text{Cs}$ in their sampling for several years. Though their MDA is higher than what the test site is looking for, it shows that the levels of $^{137}\text{Cs}$ are very low in Southern Nevada and that levels seen at the NDRA are not of any concern.

When comparing $^{137}\text{Cs}$ levels collected at the NDRA vs other places around the world there are a couple of studies to note. A. Fannu looked at natural and artificial radioactivity distribution
in soil, rock, and water of the central Ashanti Gold mine, Ghana. Twenty soil/rock samples were taken from all different areas of the mine. In this study $^{137}$Cs ranged from 0.14-27.8 Bq/kg (Faanu, 2013). In comparison in the samples tested from the NDRA $^{137}$Cs ranged from 2.14-37.37 Bq/kg. Though globally speaking Ghana is near Algeria, where weapons testing occurred, it is still far enough away (more than 500 km) to not be considered in a local fallout range. Moreover, this study compared itself to other similar studies around the world and found that its levels of $^{137}$Cs are mainly due to background levels of global fallout, with no significant contribution any other source. This is a fairly important statement because the NDRA samples have a very similar activity. The other study of note is by T. Hamilton, who looked at the $^{137}$Cs content of soil collected from Boeing North America, Inc., employees’ recreation and fitness center in Canoga Park (CA). In this study the average concentration of $^{137}$Cs collected from 35 surface soils all ranged from 0.6 to 10 Bq/kg. This was then compared to another study by McLaren-Hart that took and extensive radiological survey around Southern California. It was found that these two studies have very similar activity levels for $^{137}$Cs. Though this comparison and other the author concluded that the levels of $^{137}$Cs at the recreation center was from global fallout and not from any other source (Hamilton, 1997). This is of note because the activities in the samples found in at the recreation center and those found at the NDRA are very similar in activity. These studies in conjunction with the fact that monitoring program around Nevada, shows that the levels of cesium seen at the NDRA are mostly likely from global fallout and not from NNSS.
CHAPTER 6. CONCLUSIONS

6.1 Overview

There does appear to be a correlation between particle size and radionuclide as well as soil type and radionuclide. The data shows that for two of the three soil types, $^{137}$Cs would only attach to particles PM60 in size or less. Furthermore, a general trend is noticed that as particle sizes go down activity goes up. Along with other studies that observed a similar trend, the results presented here provide further evidence that particle size does in fact affect the concentration of radionuclide. For soil type and radionuclide there is a noticeable change in activities between the different soil types. However, this is mostly based on the natural elemental composition of the soil. The Nellis Dunes Recreational Area does not appear to have any evidence of increased long-lived fallout. The origin of $^{137}$Cs found at the NDRA appear to be caused by global fallout. This is believed because the levels found in the soil are similar to those found in other locations that are outside of local fallout range of nuclear weapons testing. Furthermore, there is a chance that little to no fallout fell on the NDRA originally. Though the NDRA is within the ‘local’ fallout range of the NNSS, there is one large factor that would have prevented most local fallout from landing on the NDRA. Because of the NNSS proximity to Las Vegas it was decided early on that nuclear weapons tests would only be conducted when the wind was coming from the southwest (Fehncer, 2000). This means that when a test occurred most of the fallout in the air would be blown in northwest direction, away from the Las Vegas and the NDRA.

When looking at the lung dose, the annual limit that the NRC sets down for the general public is 0.1 rem a year. Furthermore, Americans receive around 0.62 rem a year as background radiation. Half of which is natural background radiation and the other half is due to man-made sources of radiation such as medical x-rays. The highest dose calculated from spending a year out at the
NDRA was .684 milli-Sv or 0.0684 rem. This is a conservative estimate and the actual dose is likely to be much lower. Even with the largest dose used, the dose still falls below the annual limit that the NRC has set down for the general public and would only make up for a tiny fraction of the background dose Americans receive each year. Because the dose from inhaling dust at the NDRA is lower than the limit, even with conservative estimates, the risk of harmful radiological uptake is essentially non-existent.

6.2 Recommendations for Future Studies

There are a couple of recommendations for future studies on this topic. First, more samples should be tested, both with varying in particle size and soil types. The tests performed for this thesis were carried out using only large particles of dust. It would take far too long to prepare more samples for this thesis, but it would be beneficial to investigate particles sizes of 10 micrometers, 5 micrometers, 3 micrometers, 1 micro meters, and if possible .5 micrometers. This would be for the best because not only would particle sizes of these size penetrate deeper into the lung, giving people a larger exposure, but those dust particles are far more likely to be kicked up and remain suspended long enough for people to breath them in. Next, more soil types should be tested. Dr. Buck’s and Dr. Gooseens’ were able to identify 17 different surface types, whereas this thesis only tested three of those surface types. Though soil type had a smaller effect than particle size it was still noticeable and should be further investigated. Moreover, more data needs to be conducted on dust sample 26. Several theories were given as to why this sample has the most $^{137}$Cs, but without more research, no definite answer can be given.

Second, it would be important to obtain the amount of dust in the air out at the NDRA. Specifically, the amount of dust someone would breath in while out driving in the NDRA. The amounts used for the lung dose model were based off an experiment found in Buck et al. 2014.
Though these numbers were helpful in creating a model, the conditions set for the drivers were not exact to what conditions might typically be. For instance, the drivers were told to keep a distance of 10 to 15 meters and to keep and average speed of around 10 mph. To make a more accurate model both more distances and speeds should be tested to get more data points.
APPENDIX A. GAMMA SPECTRUM OF EVERY SAMPLE

Figure 22. Gamma spectrum for dust sample 11, PM 125-60
Figure 23. Gamma spectrum for dust sample 11, PM 250-125

Figure 24. Gamma spectrum for dust sample 11, PM 500-250
Figure 25. Gamma Spectrum for dust sample 11, PM 1000-500
Figure 26. Gamma spectrum for dust sample 11, PM 2000-1000
Figure 27. Gamma Spectrum for dust sample 15, PM 60
Figure 28. Gamma Spectrum for dust sample 15, PM 125-60

Figure 29. Gamma spectrum for dust sample 15, PM 250-125
Figure 30. Gamma spectrum for dust sample 15, PM 500-250

Figure 31. Gamma spectrum for dust sample 15, PM 1000-500
Figure 32. Gamma spectrum for dust sample 15, PM 2000-1000

Figure 33. Gamma spectrum for dust sample 26, PM 60
Figure 34. Gamma spectrum for dust sample 26, PM 125-60
REFERENCES


Goossens, D., Buck, B., McLaurin, B. (2012). Contributions to atmospheric dust production of natural and anthropogenic emissions in a recreational area designated for off-road


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