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Comparative Gamma Radiation Analysis by Geographic Region

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Summary

Gamma radiation is a high-energy form of ionizing radiation. The recent Fukushima nuclear accident highlighted its significance. This study was conducted in two parts: Part A and Part B. Gamma radiation was measured using a Geiger counter. For Part A, the Pittsburgh, Pennsylvania area was studied to determine if a city center contains higher gamma radiation levels than city outskirts. The data were also analyzed to determine which of the sources tested- metal, concrete, or vegetation- showed higher gamma radiation readings. The City of Pittsburgh had gamma radiation levels approximately equal to its surrounding environs. None of the three sources of materials tested showed consistently higher levels of gamma radiation than the others. For Part B, gamma radiation levels were measured at sites in six states and five foreign countries. These levels were analyzed for a correlation between gamma radiation and the following factors: elevation, Earth's crust thickness, county cancer rates, and, proximity to the nearest nuclear power plant. A statistical analysis was performed, including a linear correlation t-test. Elevation showed a very strong positive correlation to gamma radiation but when just elevation data from under 2500 m was analyzed, the evidence found was not as strong. The Earth's crust thickness showed no correlation. The gamma radiation levels in comparison to cancer mortality rates by U.S. county per 100,000 people had no correlation. The data showed that measurements made closer to nuclear power plants equated to slightly reduced radiation levels. A significant radiation source at Soda Springs, California was also discovered.

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Introduction

Gamma radiation is a high-energy type of electromagnetic radiation that has a particularly short wavelength and a particularly high frequency (1). Gamma radiation can be produced by an action as small as a single photon emission from a single atomic nucleus or as large as a hypernova, the most powerful astronomical event known (2). This form of radiation can be produced naturally by the environment, as well as by human-produced sources (3).

Gamma radiation is adept at penetrating the human body and other organic and inorganic materials. As a gamma ray passes through a human body, the energy of the radiation can cause the release of an electron or electrons from a given atom. This release makes an atom very unstable, and the unstable atom is referred to as a radical (4). These radicals react with other normal molecules and break their chemical bonds. The damage to these cells can result in a breakage of the deoxyribonucleic acid (DNA) in a cell. The damage is, in some cases, repaired. In other cases the damage causes chromosome aberrations, mutations, or cell death. This can lead to increased susceptibility to disease and, potentially, death (5).

A human being who is exposed to abnormally high gamma radiation levels throughout the course of his or her life could experience more cell damage than another who is not as substantially exposed (5). Determining factors in one's life or in the environment that can significantly reduce gamma radiation exposure may lead to interventions that can reduce damage to cells. An example of extreme radiation exposure is the Fukushima Daiichi Nuclear Power Plant incident in Japan.

In Japan in March of 2011, the Fukushima Daiichi Nuclear Power Plant suffered a partial meltdown of its reactor core and discharged gamma radiation into the environment, causing approximately 300,000 people to evacuate the area. Three of its nuclear reactors were compromised. This event occurred because of an earthquake measuring 9.0 on the Richter magnitude scale and the subsequent tsunami that followed which ravaged much of Japan (6). This international emergency made many people concerned about nuclear radiation. The radiation discharge was so severe that in some cases the radiation itself was visible to the human eye (7). Having knowledge of gamma radiation is of significant importance in today's world.

In this experiment, gamma radiation levels were collected using a Geiger counter that records gamma radiation in microsieverts per hour (μSv/hr). A sievert is the SI unit for measuring ionizing radiation (8). A variety of geographic regions were tested and the measurements were evaluated against different factors. This experiment was handled in two parts, Part A and Part B. In Part A, measurements were recorded at various distances from the city center of Pittsburgh, Pennsylvania. These locations were identified ahead of time using a global positioning system. Results were recorded for the gamma radiation levels of metal, vegetation, and concrete at the sites. Part B focused on recording gamma radiation levels in different areas around the world. Data were collected in North America in California, Texas, Ohio, Pennsylvania, West Virginia, Virginia, and Ontario. In Europe, data were collected in

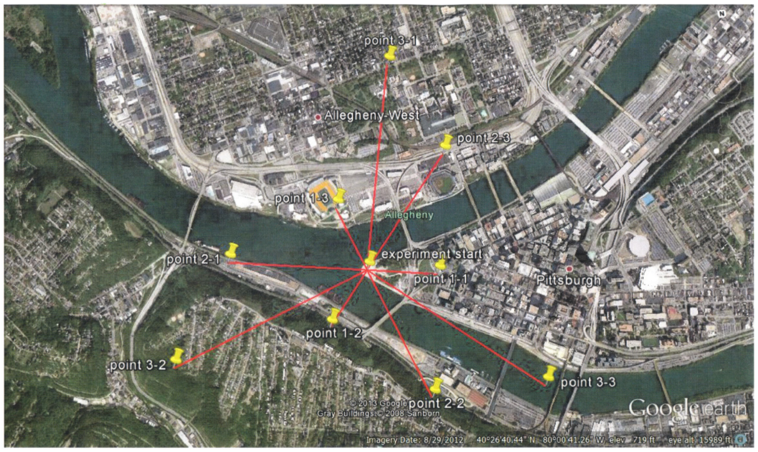

Figure 1: Map of data points for Part A of the experiment for rings 1 through 3. The first number is the ring and the second number is the point itself. At each point three samples were taken (metal, concrete and, vegetation).

various locations in France, Belgium, Luxembourg, and the Netherlands. Some limited data were also collected at various elevations during plane rides. Those data were then compared against four different factors at these geographical points: elevation above sea level, the approximate thickness of the Earth's crust, the cancer mortality rate in the county in which the measurement was taken (this test excluded the data points in Canada, Europe, and in planes as comparable cancer studies could not be found), and the distance from the nearest nuclear power plant. The importance of looking for a relationship between these factors and radiation is that they could allow for a better understanding of the factors that contribute to the amount of radiation that penetrates human bodies. Understanding this relationship could allow for a smarter and safer populace. The purpose of this study was to determine if there is a direct relationship between levels of gamma radiation recorded and the factors listed above and to attempt to understand the variables that affect the radiation levels that humans are exposed to.

In Part A, the hypothesis was that there would be higher gamma radiation levels within the City of Pittsburgh than on the outskirts. Higher amounts of metal in the city could result in higher radiation levels. The possibility of trace amounts of radioactive elements present in the metal or building materials could possibly cause this (9). It was also hypothesized that metal will have higher radiation levels than the other two testing samples (concrete and vegetation).

Part B of this experiment brought in a much broader population than Part A. Part B consisted of four hypotheses. Firstly, it was hypothesized that the presence of higher gamma radiation would correspond with higher elevation. This is believed because less of an atmosphere at higher elevations allows for less protection from cosmic rays and other forms of extraterrestrial radiation. Secondly, it was hypothesized that the presence of higher gamma radiation would correspond with thinner Earth crust. This is because the heat from the mantle is produced from radioactive decay and a thinner crust could contribute to higher radiation levels. Thirdly, it was hypothesized that the presence of higher gamma radiation would correspond with higher cancer mortality rates. This is because areas with higher cancer levels could be caused by an unknown factor that is producing radiation. Lastly, it was hypothesized that the presence of higher gamma radiation would correspond with closer proximity to nuclear power plants. This was because radiation leakage from nuclear power plants could contribute to higher levels.

A statistical linear correlation t-test was used to analyze the results. Analysis discovered a statistically significant relationship between higher elevations and increased gamma radiation, as was hypothesized. The approximate thickness of the Earth's crust failed the statistical test used and had no detectable relationship with gamma radiation levels. Cancer mortality rates showed no statistical significance to gamma radiation levels in the environment. Closer proximity to a nuclear power plant equated to slightly reduced radiation levels.

Results

The purpose of Part A was to determine the levels of gamma radiation in Western Pennsylvania. Data were collected across six days and the data locations were logged on maps (**Figure 1**). The relationship between

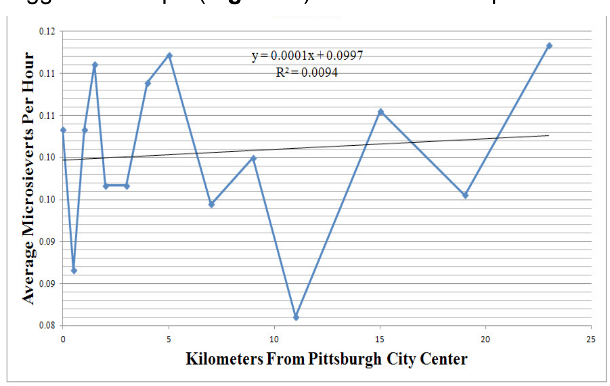

Figure 2: Scatter plot of the average radiation levels recorded at each ring plotted against each ring's distance from the city center with a line of best fit.

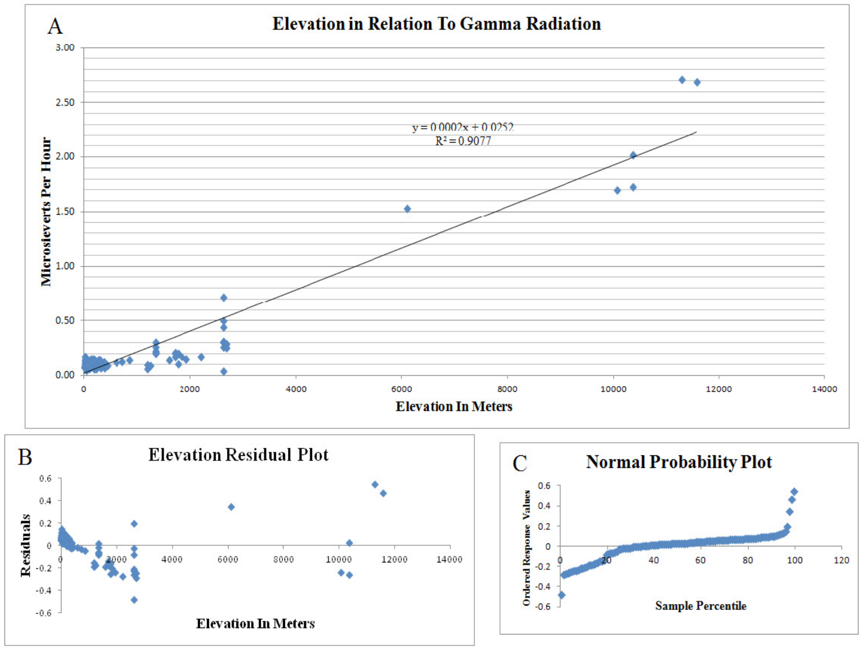

Figure 3: A. Scatter plot of the elevation data against radiation levels with a line of best fit. **B.** Residual plot of the elevation data. **C.** Normal probability plot of the elevation data.

the distance from the city center and the microsieverts per hour were recorded for each of the three types of samples (metal, vegetation, and concrete). The points for Part A were chosen by using a systematic ring system in which equidistant locations were chosen along each ring. A total of 120 readings were taken covering an approximate area of 1662 square kilometers surrounding Pittsburgh.

The data recorded within the Pittsburgh area fell within a relatively narrow range of 0.06 microsieverts per hour (μSv/hr) to 0.17 μSv/hr. These points were plotted on a graph against the distance in kilometers from the city center (**Figure 2**). Each point on the graph shows the average of the three points on each geographic ring and the three sample types of metal, concrete, and vegetation. The graph shows a very low R-squared value of 0.0094. This indicates that there is no significant correlation between the distance from the city center and microsieverts per hour recorded of gamma radiation.

The average for all metal readings in the Pittsburgh area was 0.10 μSv/hr. The averages for all concrete readings and all vegetation readings in the Pittsburgh area were also both 0.10 μSv/hr. With the proper number of significant figures used no difference between the three could be found. These data show that all three of the types of samples have approximately the same radioactivity levels.

Part B of this experiment took into account different geographical and radiological factors than Part A. All data used in Part B excluded the data gathered in Part A. The purpose of Part B was to determine if there is a correlation between gamma radiation levels and elevation, the Earth's crust thickness, county cancer rates, or the proximity to commercial nuclear power plants. On each of the four factors, linear correlation t-tests were run to determine if the samples had a pattern and the chance that one would find these results if the population was random. The highest three readings, from Soda Springs, California, were removed from the data because these outliers were misleading due to the fact that a radioactive water source independent of the factors tested produced them.

The first set of data represents the relationship between elevation in meters and microsieverts per hour (**Figure 3A**). All points less than 2500 meters in elevation were also compared (**Figure 4**). The R-squared factor for all elevations is 0.9077 (**Figure 3A**). This is quite high given that "1" is a perfect correlation. This supports the hypothesis that there could be a pattern between elevation and microsieverts per hour. A statistical linear correlation t-test was run to determine if such a correlation exists (10). The H_o, as default, is that in the population there is no correlation between microsieverts per hour and elevation (P>α). The H_a, or alternative hypothesis, is that there is a correlation between microsieverts per hour and elevation (P<α). **Figure 2B** shows the residual plot and indicates that there is no pattern. **Figure 2C** shows the normal probability plot. There is an approximate line on the plot. The P-value for these data is less than 0.001; that is less than a 0.1% chance that with a random population one would find these results. The conclusion states that assuming that H_o is correct, one would expect to see the results of the sample, where t=32.58 or more extreme, less than 0.1% of the time. Using these data, one can say that the data are statistically significant (P< α).

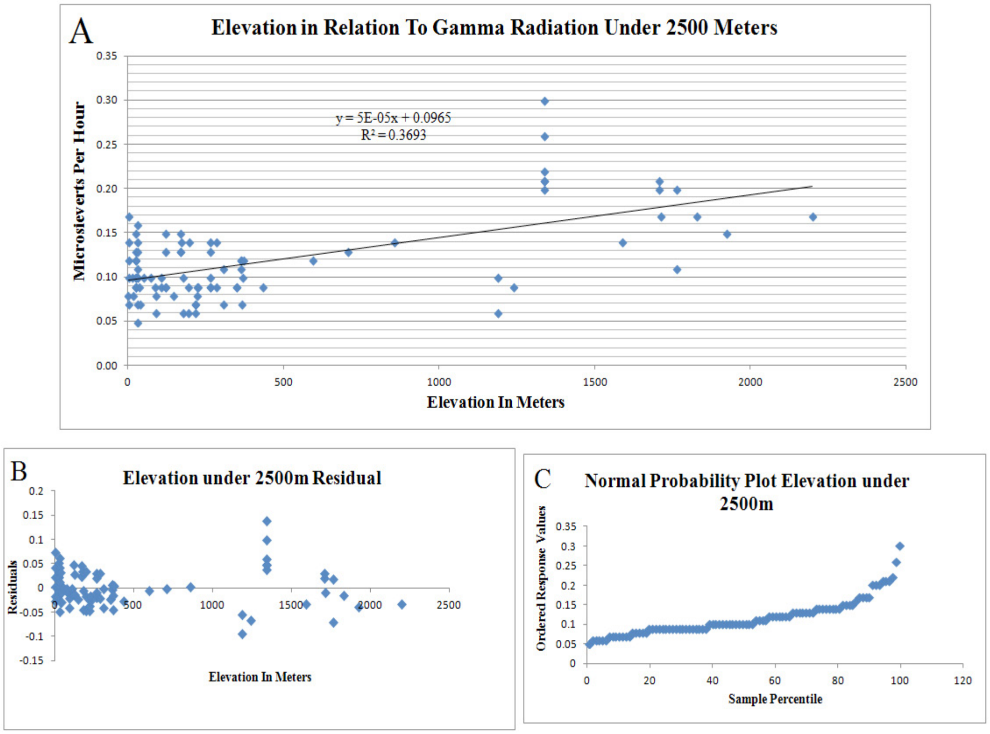

Figure 4: A. Scatter plot of the elevation data against radiation levels for data under 2500 m with a line of best fit. **B.** Residual plot of the elevation data for under 2500 m. **C.** Normal probability plot of the elevation data for less than 2500 m.

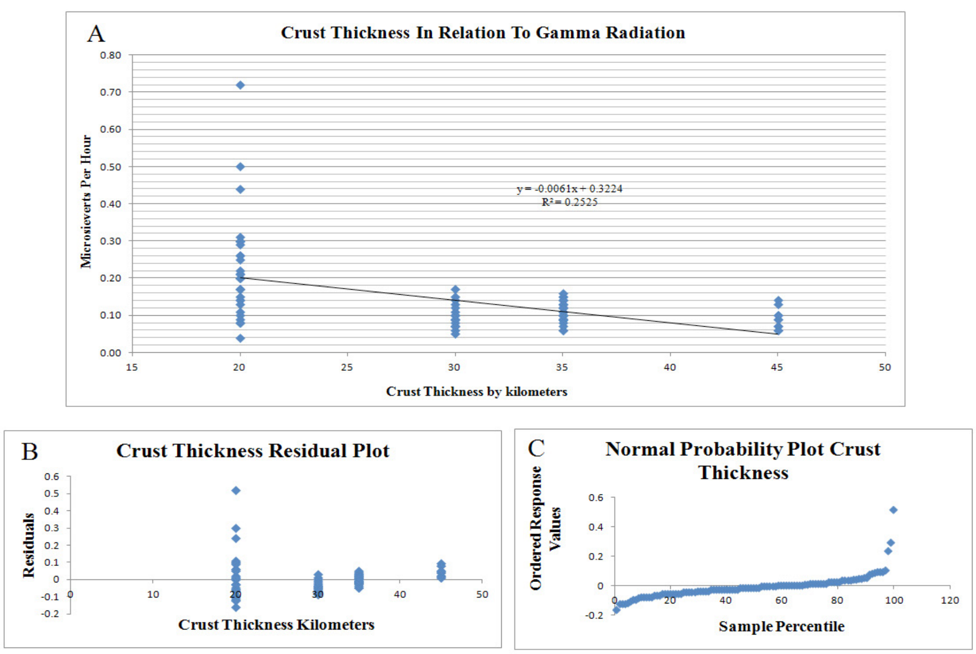

Figure 5: A. Scatter plot of the Earth's crust thickness data against radiation levels with a line of best fit. **B.** Residual plot of the Earth's crust thickness data. **C.** Normal probability plot of the Earth's crust thickness data.

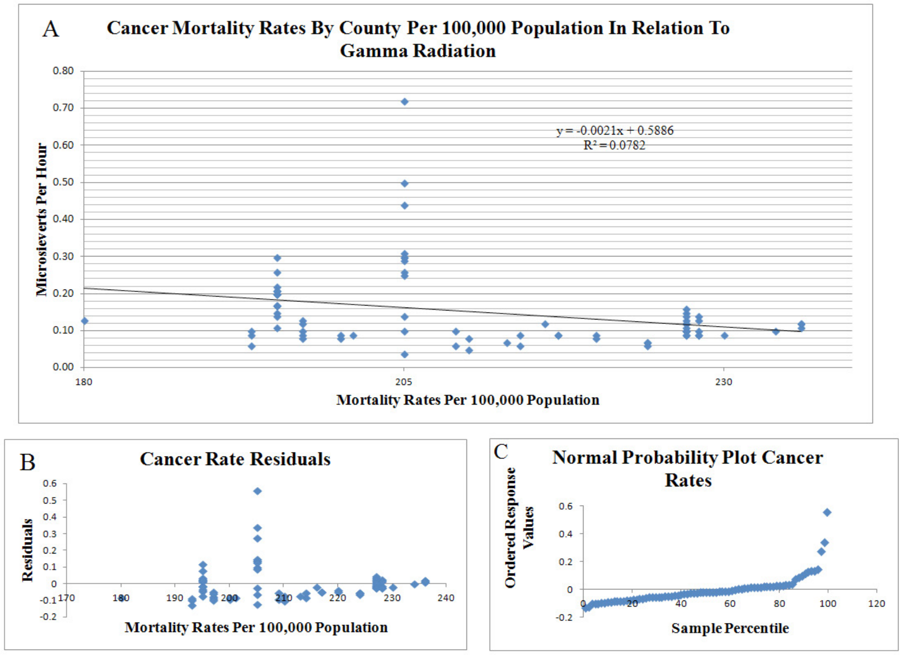

Figure 6: A. Scatter plot of the cancer mortality rates by county per 100,000 population data against radiation levels with a line of best fit. **B.** Residual plot of the cancer data. **C.** Normal probability plot of the cancer data.

The data for elevations less than 2500 m was also analyzed with a linear correlation t-test (**Figure 4A**). The H_o and H_a were the same as with the entire elevation data set. The residual plot data is scattered without a definitive line (**Figure 4B**). The normal probability plot has a line without outliers but curves off to some degree at the end (**Figure 4C**). With a t-value of 7.339 and assuming that H_o is correct, one would expect to see the results of the sample less than 0.1% of the time. This result is the same as the full elevation data and gives evidence against H_o. The real difference between the two sets is the R-squared value. The elevation data for elevations of less than 2500 m R-squared is 0.3693, as opposed to 0.9077 for the full elevation data set.

The second set of data analyzes the relationship between the Earth's crust thickness and microsieverts per hour. Plane ride data points were excluded from this particular analysis. **Figure 5A** represents the crust's thickness in relation to microsieverts per hour. The crust thickness of 20 kilometers has the most number of points in it and the most varied levels of radiation. The R-squared value for this graph is 0.2525. This is a relatively low correlation that makes it relatively hard for the line to predict the actual points. This alone supports the idea that there is no correlation between Earth's crust thickness and microsieverts per hour. The t-test was also run on this data set. The H_o is that there is no correlation between the earth's crust thickness and microsieverts per hour ($P>\alpha$). The H_a in this experiment is that there is a correlation between the Earth's crust thickness and microsieverts per hour. This sample set did not meet the proper specifications for the t-test. First, the fact that the points only occurred on four Earth's crust thickness levels somewhat diminished the reliability of the data and compromised the random sample. The reason for the points only occurring on those four particular levels is due to the fact that the U.S. Geological Survey map only had the Earth's crust thickness marked in 5-kilometer gradations (11). Second, the residual plot had somewhat of a pattern (**Figure 5B**). This caused the second of the three tests to fail. The normal probability plot did, for the most part, have a line (**Figure 5C**). The failure of two out of the three tests caused the test to fail. This, therefore, supports H_o that there is no correlation between the Earth's crust thickness and microsieverts per hour.

The third data set analyzes the relationship between cancer mortality rates by county per 100,000 people in relation to gamma radiation (12). Only points inside the United States that were not taken in planes were used. **Figure 6A** represents cancer mortality rates by county in relation to gamma radiation. The R-squared for this graph is 0.0782. This is very low and shows that the line of best fit is not good at predicting the correct points on the line, indicating that there is no linear relationship between cancer mortality rates by county and microsieverts per hour. A t-test was also run for this set of data. The H_o is that there is no correlation between cancer mortality rates by county and microsieverts per hour ($P>\alpha$). The H_a is that there is a correlation between cancer mortality rates by county and microsieverts per hour ($P<\alpha$). These data pass the random sample test. These data also pass the residual plot due to the fact that there is not a real pattern in the residuals (**Figure 6B**). Lastly, there is a substantial line in the normal

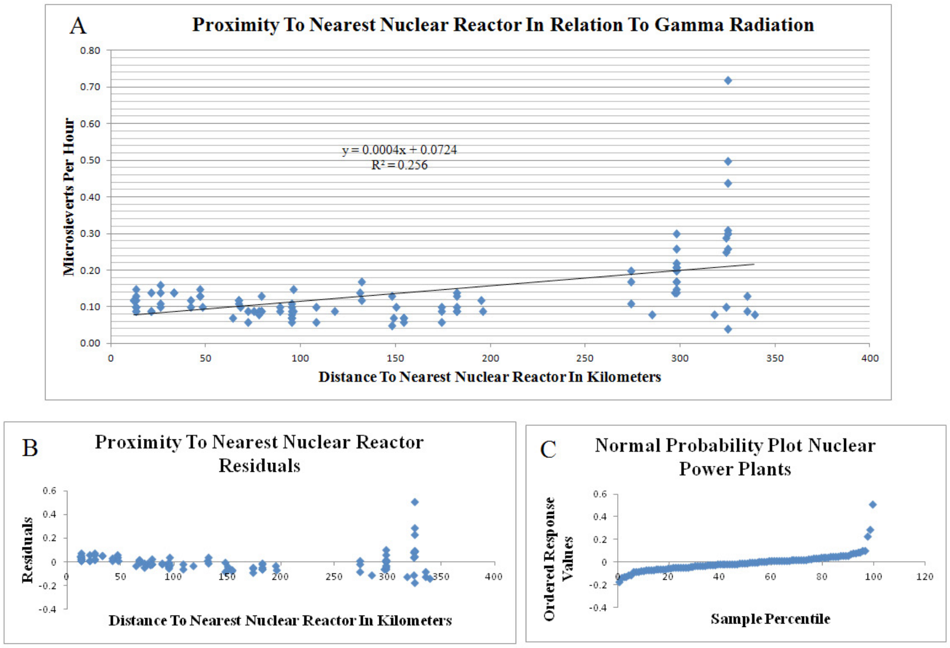

Figure 7: A. Scatter plot of the proximity to nearest nuclear reactor data against radiation levels with a line of best fit. **B.** Residual plot of the proximity to nearest nuclear reactor data. **C.** Normal probability plot of the nearest nuclear reactor data**.**

probability plot (**Figure 6C**). The P-value is 0.015. This means that there is a 1.5% chance that if the population was random that one would get these results. Assuming H_o is correct, one would expect to see the results of the sample, t=2.5055 or more extreme, 1.5% of the time. Using these data we can say that the data are somewhat statistically significant (P<α).

The fourth and final data set that was analyzed was the relationship between the proximity to the closest nuclear power plant and microsieverts per hour recorded (**Figure 7A**) (13). The points taken on plane rides were excluded. The R-squared value for this graph is 0.256, which doesn't support the hypothesis that there is a linear correlation between proximity to nuclear power plants and microsieverts per hour. The linear correlation t-test was then run on this set of data. The H_o in this case is that there is no correlation between the proximity to the closest nuclear power plant and microsieverts per hour or that P>α. The H_a in this experiment is that there is a correlation between the proximity to the closest nuclear power plant and microsieverts per hour (P<α). The data are a random sample. The data also pass the normal probability test with a distinct line in the data (**Figure 7C**). The residual plot test is harder to tell (**Figure 7B**). There is a bit of a line formation but not much. The test is continued with caution. The t-value is determined to be 5.8951. Using the t-table, the P-value of less than 0.001 is found. The conclusion states that if there is no correlation in the population (H_o is correct) one would expect to see the results of the sample of t=5.8951 or more extreme, less than 0.1% of the time. One must proceed with caution when analyzing this conclusion due to the fact that one of the tests was not passed very well. Using these data we can say that the data are statistically significant (P<α) and give some evidence against H_o.

Discussion

The points gathered in this study help shed light on factors that can contribute to human radiation exposure. Over a course of three weeks for Part A, 120 points of data at 40 locations were gathered (**Figures 1 and 2**). The operating manual provided with the Geiger counter states that the average background radiation level should be less than 0.30 μSv/hr (14). All of the readings in Part A were far below this number, with the highest being only 0.17 μSv/hr. It is possible that the average radiation levels may be higher in the Ukraine, where the Geiger counter was made, than in the United States. This is where the Chernobyl nuclear power accident happened in 1986. Over the years an estimated 16,000 people have died as a result of this accident (15). Contrary to the hypothesis, gamma radiation levels did not go down as the distances got farther away from the city (**Figure 2**). There appears to be no discernible pattern in the data (**Figure 2**). Another hypothesis that was deemed to be invalid was that metal would have the highest average reading. With the proper number of significant figures in use, there was no difference found between the three types of readings.

Part B of this experiment allowed for a much broader representation of radiation as a whole due to a larger population of points in North America and Europe. As mentioned previously, elevation, the Earth's crust thickness, cancer mortality rates per 100,000 people, and the proximity to nuclear power plants were all cross-referenced to the microsieverts per hour. A linear correlation t-test was run on all the data.

The results for elevation conformed to the hypothesis (**Figure 3**). The R-squared value of 0.9077 indicated that there was a very strong correlation between elevation and the microsieverts per hour that showed that the higher the elevation, the higher the microsieverts per hour. The t-test results substantially supported the hypothesis. This research, though, does not explain why there is this correlation. It may be that the higher one goes in elevation, the thinner the atmosphere becomes. A thinner atmosphere causes less protection from cosmic rays, which have high levels of radiation (16). The highest elevation point was over New Brunswick, Canada at 11,581 meters above sea level. This location's radiation level was 2.69 μSv/hr. This was a significant increase from many lower elevations that had readings around 0.10 μSv/hr.

The elevation data showed strong evidence against H_o (**Figure 3**). But, the points above 6000 m are sparse and could be outliers. When the lower of the two regions was identified and analyzed, it painted a different picture for the conclusion of the elevation data. The under-2500 m data did still give strong evidence against the H_o, although it had a low R-squared value of 0.3693. This value causes the results of the full elevation data to be accepted with some level of caution because the data over 6000 m could have been outliers.

Unfortunately, not much information from the Earth's crust data could be gleaned (**Figure 5**). The R-squared value was 0.2525, which is too low to make comfortable predictions. If a more in-depth study was done perhaps the data could be brought to more of a conclusion.

For the cancer rate data (**Figure 6**), there is no linear correlation. This is contradictory to the original hypothesis. The reason could be that the data are not a fair representation of the population. Radiation in the past has been linked to thyroid cancer, especially among children. After the Fukushima accident, spikes in childhood thyroid cancer occurred (17). Further analysis is required for a more reliable conclusion. With the R-squared value so low it is not a particularly good indicator to show if there is a relationship and negates the result of the linear correlation t-test.

For proximity to nuclear power plant data (**Figure 7**) the R-squared value was 0.256. The t-test determined that there was less than a 0.01% that if the population was random that one would get these results. This result, though, is not perfect and it needs to be understood with caution when analyzing the data due to the fact that one of the statistical tests failed. The data showed that the farther away from a nuclear power plant, the greater the gamma radiation becomes. This goes against the original hypothesis. These data could possibly be skewed and not a fair representation of the population.

The most startling discovery made in this entire experiment were the results discovered in a small spring at Tuolumne Meadows in Yosemite, California, USA in the spring water. This spring is referred to as Soda Springs due to the fact that it produces natural carbonation in the spring water (18). At this spring, unusually high gamma radiation was discovered. The highest reading came in at around 32 times higher than the normal average of 0.10 μSv/hr that was usually recorded. The highest reading at the spring was 3.20 μSv/hr. A large number of results were recorded at this spring. It is unknown why these readings were so high. A study done in 2008 in Poland linked underground spring mineral water to higher alpha and beta radiation. That study points out that while there may be benefits in certain mineral waters from increased concentrations of magnesium, calcium, and other elements, these increases can also be associated with higher concentrations of naturally occurring radioactive isotopes of radium, uranium, and other radioactive elements (19).

There was one other (non-carbonated) spring tested in the original data from West Virginia. Its gamma radiation level of 0.10 μSv/hr was similar to its surroundings and indicated nothing unusual. As a follow up test, a non-carbonated spring in Pennsylvania was found to have a similar reading of 0.09 μSv/hr, again indicating nothing unusual. Possible hypotheses are that the rocks through which the Soda Springs water passes contain high levels of radiation or that somehow the process of carbonating concentrates radiation levels.

In any experiment or study, errors are unavoidable and some can be addressed in follow- up studies. One possible error is that the plant and metal types were never specified. The most substantial piece of each material that could be found at each global positioning system location was tested. This, therefore, could not have given perfect results because different plants or metals

Country	City	Number of data points
Belgium	Bruges	1
	Brussels	3
Canada	Toronto	3
France	Paris	12
	Metz	2
Luxembourg	Luxembourg City	1
The Netherlands	Amstel	1
	Amsterdam	2
	Volendam	1
	Marken	1
U.S.A.	Houston, TX	1
	Williamsburg, VA	9
	Toano, VA	4

Country	City	Number of data points
U.S.A.	Berlin, PA	1
	Pittsburgh, PA	2
	Dallas, TX	2
	Wheeling, WV	3
	Columbus, OH	5
	Zanesville, OH	3
	Groveland, CA	1
	Yosemite, CA	25
	Giant Sequoia Park, CA	3
	Tracy, CA	1
	San Francisco, CA	4
	Stinson Beach, CA	1
	Dolly Sods State Park, WV	3

Country	City	Number of data points
U.S.A.	Elkins, WV	1
	Buckhannon, WV	1
	Morgantown, WV	1
	Central Garage, VA	1
	Warrenton, VA	2
	Westlake, OH	1
	North Ridgeville, OH	2
	Richfield, OH	1
	Mantua, OH	1
	Evans Lake, OH	1
Plane Rides		9

Table 1: List of all data pints for Part B broken down into country and city where they were collected.

could contain different radiation levels on average. A second possible error is the sensitivity of the Geiger counter. The Terra-P Geiger counter only records to the hundredth of a sievert. A more sensitive Geiger counter could be able to detect more minute changes in radiation levels. For example, in Part A when the three sample types were identified, a Geiger counter with a higher sensitivity could detect small changes in the sample types by going beyond a hundredth of a sievert. Ideally, a follow-up experiment would contain more readings and would limit the total number of variables by using the same types of metals and plants. It would also be beneficial to take multiple data points at each location for each sample type to get a better average and reduce outliers. As previously mentioned, the U. S. Geological Survey map used for the earth's crust thickness was not highly detailed. The map categorized crustal depths across relatively large geographical areas. There could be variations in the earth's crust thickness that were not recognized (11). Another potential area of error is that a perfect simple random sample was not able to be used for the locations of the data points, even though the t-test called for it, because of limited means. A true simple random sample would have allowed for any point to be randomly chosen anywhere in the United States. Many of these locations are inaccessible.

One item that warrants mention is the consistency in readings that occurred in areas as far apart as 8800 kilometers. If one removes the readings at high elevations as well as the outliers at Soda Springs, California, one will see an overall general consistency in microsieverts per hour. Gamma radiation levels were generally consistent between San Francisco and Brussels, Belgium. The measurements in Dallas and Houston were roughly equivalent to those in Luxembourg City and Metz, France. The small town of Volendam, the Netherlands, had readings similar to Toronto, Canada. The levels in Amsterdam and Paris were generally similar to those in Dolly Sods, West Virginia and Central Garage, Virginia. This is not to imply that all measurements were identical to each other; it is meant to point out that gamma radiation in Europe's Low Countries isn't, for example, twice as high as measurements taken on the West Coast of the United States or in the Appalachian forests.

Methods

This experiment recorded data samples of radiation in the Greater Pittsburgh Area for Part A, and radiation samples from other areas around the world for Part B. These readings were all taken by the first author. A Terra-P Geiger counter purchased from the Ukraine was used for this experiment. When data was being collected, only gamma radiation was recorded. The Geiger counter only records beta and gamma radiation; a detachable plate on the back of the Geiger counter was attached to block beta radiation.

Part A

This experiment started at the confluence of the Allegheny and Monongahela rivers in the center of Pittsburgh, Pennsylvania. At this location, measurements for vegetation, concrete, and metal samples were taken. From there, a geographic ring was plotted at the 0.5 kilometer mark from this center point. This ring contained the next three testing sites, equidistant from each other along this ring. The ring was then expanded by 0.5 kilometers again and the samples were taken from the three points farthest away from the previous three points. For example, if a point on the first ring one had a heading of 0 degrees, then the next two points would have headings of 120 degrees and 240 degrees, respectively. On the next ring, moving outward, the first point would have a heading of 60 degrees (which is in between the 0 and 120 degrees on the first ring). The second point on this ring would have a heading of 180 degrees. This concept continued for all of the expanding rings. After four of these 0.5 kilometer expanding rings, the ring size was changed to moving outward one full kilometer per ring, for three more rings. Then the ring size expanded to two kilometers per ring, three times. Finally, the ring size was expanded to 4 kilometers per ring and this was repeated three times. At each site, one measurement of each of the three sample types was collected. About 15 to 20 seconds was needed to record a sample type at each point. At each site, latitude and longitude coordinates were recorded. All of the data were then recorded in Google Earth software from which maps were produced (20). See Figure 1 to view the data points and the ring system.

Part B

In Part B, readings of ambient air or material that was nearby, be it plant, concrete, or metal, were taken. The procedure was to place the Geiger counter at the desired spot and record the data. This, on average, took about thirty seconds per data point. Separate charts were made for how microsieverts per hour relate to each of the following: elevation, Earth's crust thickness, cancer rates, and proximity to commercial nuclear power plants (**Figures 3-7**). The information on elevation was gathered from Google Earth at each location (20). For the Earth's crust thickness, the depth at each point was gathered from the U.S. Geological Survey's website (11). The data on cancer rates per county was gathered from the Center for Disease Control's website (12). The location of nuclear power plants was found on the Nuclear Regulatory Commission's website (13). **Table 1** lists the country and city where the Part B points were taken and the number of points that were taken at each location.

Each of the four relationships was analyzed using a linear correlation t-test. The first step in the t-test is to determine the α, H of O (H_o), and H of A (H_a). For all tests in this study, the α is set to 0.05. α is the maximum P value that comfortably gives evidence against H_o. The H_o is that there is no relationship between the two variables. H_a is the alternative hypothesis that there is a relationship between the two variables. Step 2 of the test is that it must pass three conditions: 1) the sample must be a simple random sample, 2) the residual plot has no pattern, and 3) residuals are normally distributed on a normal probability plot (form an approximate line). Step

3 is the actual test. First the t must be determined. The equation for t is:

$$t = r\sqrt{\frac{n-2}{1-r^2}} \quad [1]$$

where represents the number of data points. In this case, t=32.58. A t-table is then used to determine the P-value. The value that is found is then multiplied by 2 to determine the correct P-value. The P-value is the probability that with a random population one would find the results that were recorded within the sample. The final step, step 4, is the conclusion.

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