State of Kansas Background Radiation Study

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Radiation Control Program

January 2017

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Abstract

The Kansas Department of Health and Environment's Radiation Control Program (RCP), in conjunction with the Kansas Environmental Public Health Tracking program (EPHT) collaborated on a radiological data collection project for the state of Kansas in July 2015 to address an identified data gap in background radiation knowledge related to natural background radiation. The data acquired is based on measurements for gamma radiation measurements and laboratory analysis of uranium, thorium, and radium activities in soil. The purpose for the collection of measurements and soil gamma spectroscopy analysis results were to establish a baseline dataset. In the future, this dataset can be used in the event of a radiological emergency, for regulatory purposes, or risk evaluation.

Acknowledgment

This report was supported by many. We thank Jason Barney and D. Shay Hannah for assistance with coordinating the sample collection process and instrument expertise. This would not have been possible without Benjamin McCaffrey for his professional work collecting measurements and samples across the state. We also thank everyone at the Iowa State Hygienic Radiochemistry Laboratory for their expedient and high quality laboratory analysis. Most of all, Kimberly Steves, Jessica Willard, and their respective departments are appreciated for supporting this project from the beginning.

Introduction

The Kansas Department of Health and Environment routinely receives requests for information regarding radiation risk from the general public. Previously the relevant data available came from the United States Geological Society (USGS) background radiation maps for gamma radiation, uranium concentrations, and thorium concentrations, which were likely generated from models based on flyover spectrometer data and not from actual samples or ground level surveys (Duval, Carson, Holman, Darnley, 2005). More exposure hazard information and specific radiation data was necessary to be able to adequately answer their questions. This type of data would also be informative when conducting environmental public health investigations. Therefore, the Kansas Radiation Control Program partnered with the Kansas Environmental Public Health Tracking program to fund, support, analyze, and display data for the background radiation project. Radiological data across the state of Kansas was collected to establish a current baseline dataset for background radiation.

This project and resulting article was supported by the cooperative agreement number, NU38EH000618-08, funded by the Centers for Disease Control and Prevention. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention or the Department of Health and Human Services.

The initial purpose of the project was to establish a baseline data set based on ground measurements for background gamma radiation levels and for uranium, thorium, and radium activities in the soil. Forty-seven sampling sites were selected to cover the state in a grid pattern. Sample locations were chosen where the soil had not been disturbed. The collection procedure was the same one utilized by the nuclear power plant environmental monitoring program within the state. Samples and survey data were collected from all the sites in 2015 and sent to a radiochemistry laboratory for analysis.

Information that was collected during and after sampling was uploaded into a system called RadResponder (www.radresponder.net), which is utilized by the Kansas Radiation Control Program for data aggregation and emergency preparedness activities. The RadResponder Network was created to support radiological response and has also served as a valuable tool for data management and quality control. Radiation Control Program staff are able to collect additional gamma radiation readings in the future to add to the database.

Analysis has been conducted and shows that gamma exposure rate data is consistent with trends depicted in the USGS terrestrial gamma ray map (Duval et al., 2005) in that exposure rates are higher towards the western half of the state. In addition to the exposure rate data, soil analysis shows that radionuclide activities are largely consistent with both the Oak Ridge National Laboratory study ORNL/TM-7343 (Myrick, Berven, Haywood, 1981), and the extensive data collected in Kansas due to nuclear power plant environmental monitoring. When comparing exposure rate data to specific radionuclide activities identified, there is no evidence to confirm correlation between any single radionuclide and overall gamma exposure rate.

Methods

Sampling Plan

The state was divided into a grid to identify an even distribution of samplings points. The grid was chosen as it corresponded well with existing roads and nearby communities. At each of the locations identified, undisturbed areas were selected. A map was created to identify locations (Appendix 1). The sampled locations are listed in Table 1:

Holton	Highland	Seneca	Alma	Olathe	Ottawa	Mapleton	Hamilton
Belleville	Randolph	Beloit	Baxter Springs	Galesburg	Geneseo	Newton	Plevna
Lucas	Caldwell	Kiowa	Kingman	Greensburg	Protection	Liberal	Elkhart
Garden City	Coolidge	Leoti	Dighton	Hanston	Otis	Alton	Smith Center
Wallace	Goodland	St. Francis	Atwood	Hoxie	Ellis	Admire	Atlanta
Abilene	Lincolnville	Norton	Oakley	Ulysses	Montezuma	Elgin	

Table 1: Sampling Locations

Gamma Exposure Rate Measurements

Exposure rate measurements were taken using two instruments; a NaL Micro-R meter (Ludlum Model 19) and a pressurized ion chamber (Victoreen 451P). Gamma readings were taken three feet above the ground surface prior to soil sampling. Instruments remained consistent throughout the data collection period and had recent calibration reports. For data analysis purposes, the exposure rates from the Ludlum Model 19 Micro-R meter were used. Each of the instruments were calibrated and read in conventional units and were converted to the International System of Units (SI) mathematically. Data was logged using the RadResponder Network application on an iPad (Appendix 2). Date, time, GPS

coordinates, meter information, height, observations, and measurement data were uploaded into RadResponder during collections to ensure consistent data throughout the process. The RadResponder Network is the product of collaboration between Federal Emergency Management Agency (FEMA), Department of Energy (DOE) / National Nuclear Security Administration (NNSA), and the Environmental Protection Agency (EPA).

Soil Sample Collection

Surficial soil samples of 1000 cm^3 were collected at each location. Samples were contained in chemically resistant polypropylene containers with matching airtight lids. Undisturbed (no visual signs of soil disturbance and away from any roadways or buildings) locations were selected. Supplies were decontaminated after each sample to prevent cross contamination. To allow secular equilibrium to be reached, samples remained sealed for a minimum of 60 days (Figure 1). The samples were then sent to the Iowa State Hygienic Laboratory for analysis by both gamma spectroscopy and by inductively coupled plasma – mass spectrometry (ICP-MS) for uranium content. Sample results were reported in conventional units (pCi/kg) and converted to SI units mathematically. Both man-made and naturally occurring radionuclides were analyzed, but only those naturally occurring will be discussed in this report. Those radionuclides include: Actinium-228, Bismuth-212, Bismuth-214, Lead-212, Lead-214, Radium-224, Thorium-228, and Potassium-40.

$$t_{max} = \frac{\ln\left(\frac{\boldsymbol{\lambda_d}}{\boldsymbol{\lambda_p}}\right)}{\boldsymbol{\lambda}_d - \boldsymbol{\lambda}_p}$$

where λ_p = decay constant of parent; and λ_d = decay constant of daughter

Figure1: Equation to calculate time to reach max activity of radioactive daughter

Results

Gamma Exposure Rates

The Ludlum Model 19 Micro-R meter results ranged from 0.07 to 0.16 µSv/hr (7 to 16 µR/hr). The statewide average gamma exposure rate using the Ludlum Model 19 Micro-R meter was 0.12 µSv/hr (12 µR/hr). The Victoreen 451P pressurized ion chamber results ranged from 0.10 to 0.18 µSv/hr (10 to 18 µR/hr) with higher readings found in the north central area of the state. The statewide average gamma exposure rate using the Victoreen 451P pressurized ion chamber was 0.142 µSv/hr (14.2 µR/hr). Locations measured were logged in RadResponder (Appendix 2).

Exposure rate data tables can be found in Appendix 3. Heat maps of exposure rate readings can be found in Appendix 4.

Radionuclide Activities in Soil

Soil sample analysis resulted in ranges of activities for each nuclide depending on location. In addition to gamma spectroscopy analysis, each sample was analyzed for uranium content by ICP-MS. Results are listed in Table 2:

Nuclide	Minimum	Maximum	Unit	Minimum	Maximum	Unit
Actinium-228	15.98 ± 2.07	60.31 ± 5.85	Bq/kg	432 ± 56.2	1630 ± 158	pCi/kg
Bismuth-212	>4.22[1]	141.71 ± 5.85	Bq/kg	>114[1]	3830 ± 158	pCi/kg
Bismuth-214	13.76 ± 1.31	78.07 ± 4.55	Bq/kg	372 ± 35.4	2110 ± 123	pCi/kg
Lead-212	>0.72[1]	54.02 ± 2.58	Bq/kg	>19.5[1]	1460 ± 69.8	pCi/kg
Lead-214	15.65 ± 1.26	90.28 ± 4.92	Bq/kg	423 ± 34.1	2440 ± 133	pCi/kg
Radium-224	12.77 ± 6.51	51.8 ± 13.84	Bq/kg	345 ± 176	1400 ± 374	pCi/kg
Thorium-228	>18.32[1]	131.35 ± 43.66	Bq/kg	>495[1]	3550 ± 1180	pCi/kg
Potassium-40	61.42 ± 31.60	795.5 ± 37.37	Bq/kg	1660 ± 854	21500 ± 1010	pCi/kg
Uranium content	0.64	3.30	mg/kg	0.64	3.30	ppm

[1]minimum detectable concentration

Table 2: Minimum and Maximum Radionuclide Activity Found in Soil

Discussion

Gamma Exposure Rates

The Ludlum Model 19 Micro-R meter showed high readings further west, as expected due to geology and elevation. The Victoreen 451P pressurized ion chamber showed higher readings in the north central area of the state. The Oak Ridge National Laboratory Study (Myrick et al., 1981) found higher exposure rate readings in western Kansas, ranging from 0.14 µSv/hr (14 µR/hr) at the furthest location to the west and 0.098 µSv/hr (9.8 µR/hr) furthest to the east. The ORNL study was limited to points along Interstate 70. The USGS terrestrial radiation report (Duval et al., 2005) shows gamma-ray absorbed dose to be highest in the northern and western part of the state, consistent with the measurements from the Ludlum Model 19 Micro-R meter, but differing from those using the Victoreen 451P pressurized ion chamber. This could be due to different energy response between the instruments.

In an effort to quantify the effect of cosmic radiation on exposure rates, a correlation coefficient was calculated based on elevation change throughout the state (Appendix 8). A weak correlation coefficient of 0.3945 was found.

Isotopic Distribution of Radionuclides in Soil

Although not directly measured using gamma spectroscopy, it can be inferred that Radium-226 is in equilibrium with Bismuth-214 due to the time allowed to reach secular equilibrium (Figure 2). The activity of Radium-226 in the soil is consistent with that documented in the ORNL TM-7343 study (Myrick et al., 1981). Their results showed Radium-226 in activities from 12.58 to 51.8 Bq/kg (340 to 1400 pCi/kg) whereas the current study showed activities from 13.76 to 78.07 Bq/kg (372 to 2110 pCi/kg). Using the soil sample analysis results combined with exposure rate data across the state, correlation with these naturally occurring radionuclides could be measured. Using the data collected of all naturally occurring radionuclides, an overlay of the data was created with isotopic concentrations to determine potential correlation with exposure rate measurements (Appendix 5). No specific radionuclide had a strong correlation with exposure rates, however, there is a correlation between the summation of all natural radionuclides measured and exposure rate at any given location. A scatter plot was created showing this correlation (Appendix 5). Other factors contribute to gamma exposure rates at three feet above the ground, such as cosmic radiation or non-naturally occurring radionuclides. Correlation coefficients are listed in Table 3:

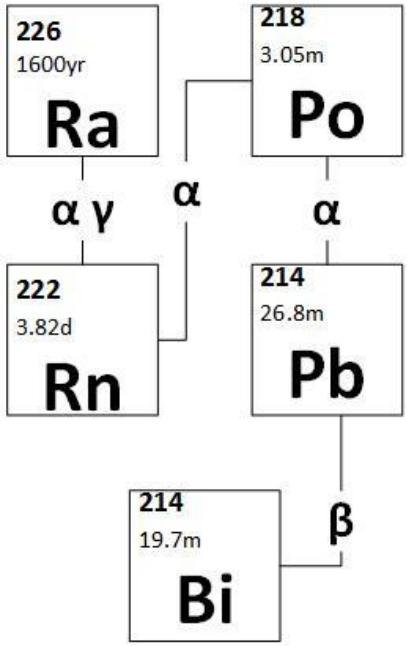

Figure 2: Decay Chain of Radium-226

Radionuclide	Correlation coefficient
Actinium-228	0.6579
Bismuth-212	0.031
Bismuth-214	0.5792
Lead-212	0.6034
Lead-214	0.5735
Radium-224	0.6204
Thorium-228	0.3001
Potassium-40	0.6158
Uranium content	0.2012
Summation of all natural radionuclides	0.7705

Table 3: Correlation coefficients of radionuclides and exposure rates

Uranium Concentration

The pattern for both exposure rate measurements and soil analysis data is consistent with previous Kansas data from both the ORNL TM-7343 study (Myrick et al., 1981) and USGS flyover gamma-ray exposure data (Duval et al., 2005). In addition, uranium concentration data collected by the USGS in the aforementioned study is comparable to the results found in the current study. The USGS study shows concentrations of uranium across the state ranging from approximately 0.7 ppm to 3.0 ppm. For this study, samples ranged from 0.64 mg/kg (equivalent to ppm by mass) to 3.3 mg/kg (Appendix 6). The average concentration across the state was 1.82 mg/kg. Using the uranium concentration data per

location, we were also able to make direct comparisons to exposure rate measurements at each location. Uranium concentration showed little correlation with the gamma exposure rate at three feet with a correlation coefficient of 0.2012 (Appendix 7).

Radon Source

Soil analyses may indicate if there are locations that are more or less likely to have radon concentrations in the soil. As noted by the Environmental Protection Agency (EPA), most of Kansas is determined to be in radon zone 1, which is the zone predicted to have average indoor radon concentration levels of greater than 4.0 pCi/L (White, 1993). The Kansas Radon Program has determined that 42.6% of homes tested in Kansas have high levels of Radon. (www.kansasradonprogram.org)

Radon is the decay product of Radium-226. Because of the decay of Radium-226 into Radon-222 gas, it can reasonably be inferred that locations with higher activities of Radium-226 have greater potential for radon emanation (White, 1993). As many factors contribute to the potential for elevated indoor radon levels in homes, such as building design, air tightness, heating and cooling systems, and weather, data collected during this study cannot be used as a predictor of elevated indoor radon levels. Maps produced using this data show the amount of source activity of the radioactive parent of Radon-222 in each of the samples collected. A map showing the activity of Bismuth-214 (in equilibrium with Radium-226) can be found in Appendix 9 along with maps produced by the Kansas Geological Survey and the Kansas Department of Health and Environment Environmental Public Health Tracking Network. The Kansas County Radon Map from the Kansas Radon Program is also included based on EPA zone levels and actual indoor radon measurements across the state.

Summary

This study comprised the collection of radiation data at 47 undisturbed locations evenly distributed across the state of Kansas. In addition to the data collected specifically for this study, additional data points can be collected by the Radiation Control Program during field activities for dataset expansion and future research. The data obtained is consistent with previous conclusions from ORNL and USGS regarding background gamma ray exposure data based on a much smaller sample size. The gridded sampling locations across the state provides a comprehensive picture of background radiation. Although slight correlation can be seen at various locations on several different radionuclides, individual radionuclides do not have strong correlation with exposure rate. The strongest correlation was found with a summation of all natural radionuclides in a given sample with a correlation coefficient of 0.7705. Cosmic radiation likely contributes, particularly in the higher elevations in the western part of the state. Expansion of data analysis including man-made contribution, mostly from fallout due to atmospheric nuclear weapons testing around the world, can be done in the future. This data also indicates radon source activity in each of these samples by quantification of Radium-226 at each location with soil analysis.

Development of this dataset and resulting analysis provides the state with an informative baseline that can be used for comparative research in the future. Most notably in any type of activity that affects radiation levels, such as technologically enhanced naturally occurring radioactive material (TENORM), transportation accidents, nuclear power plant accidents, or acts of terrorism.

References

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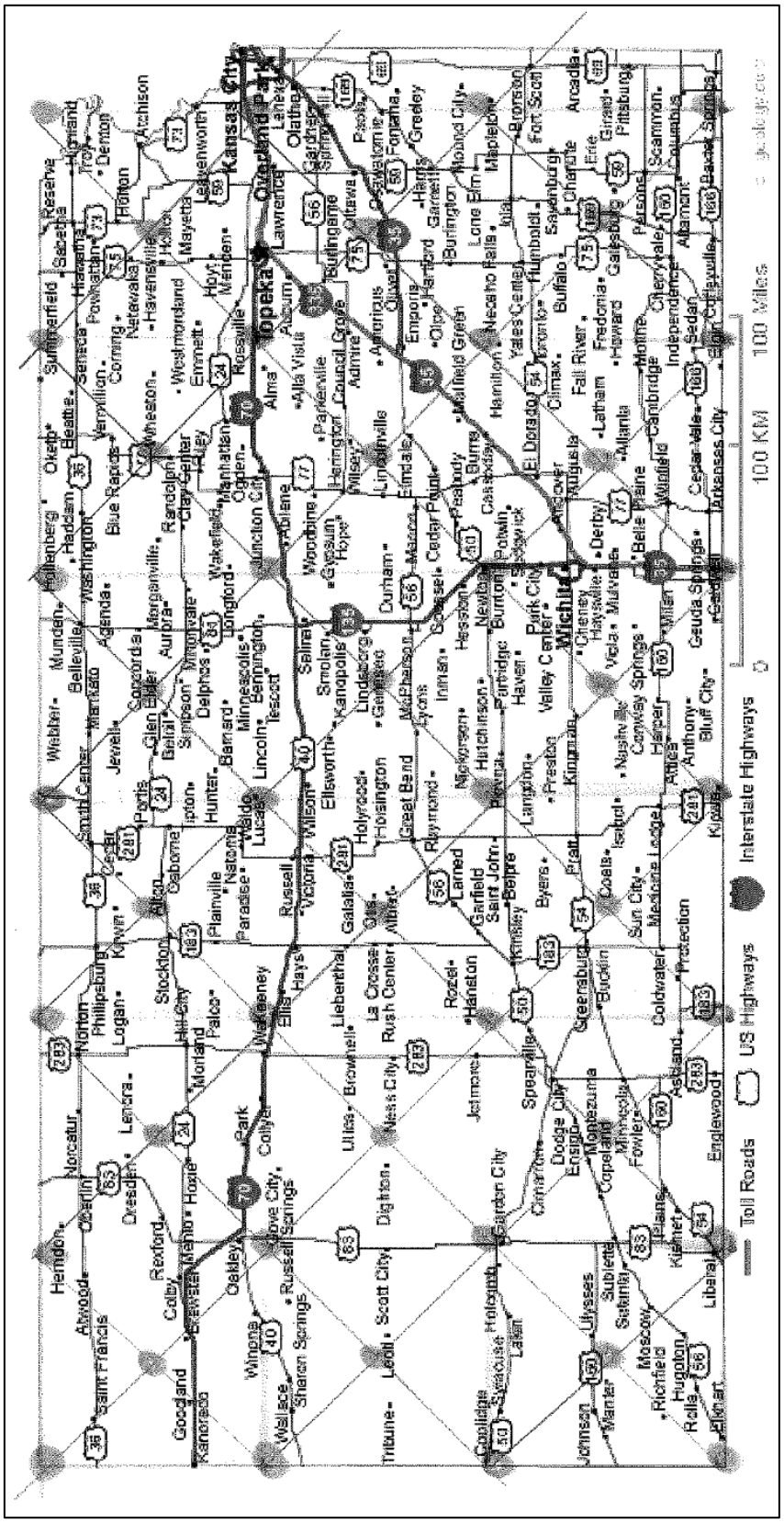
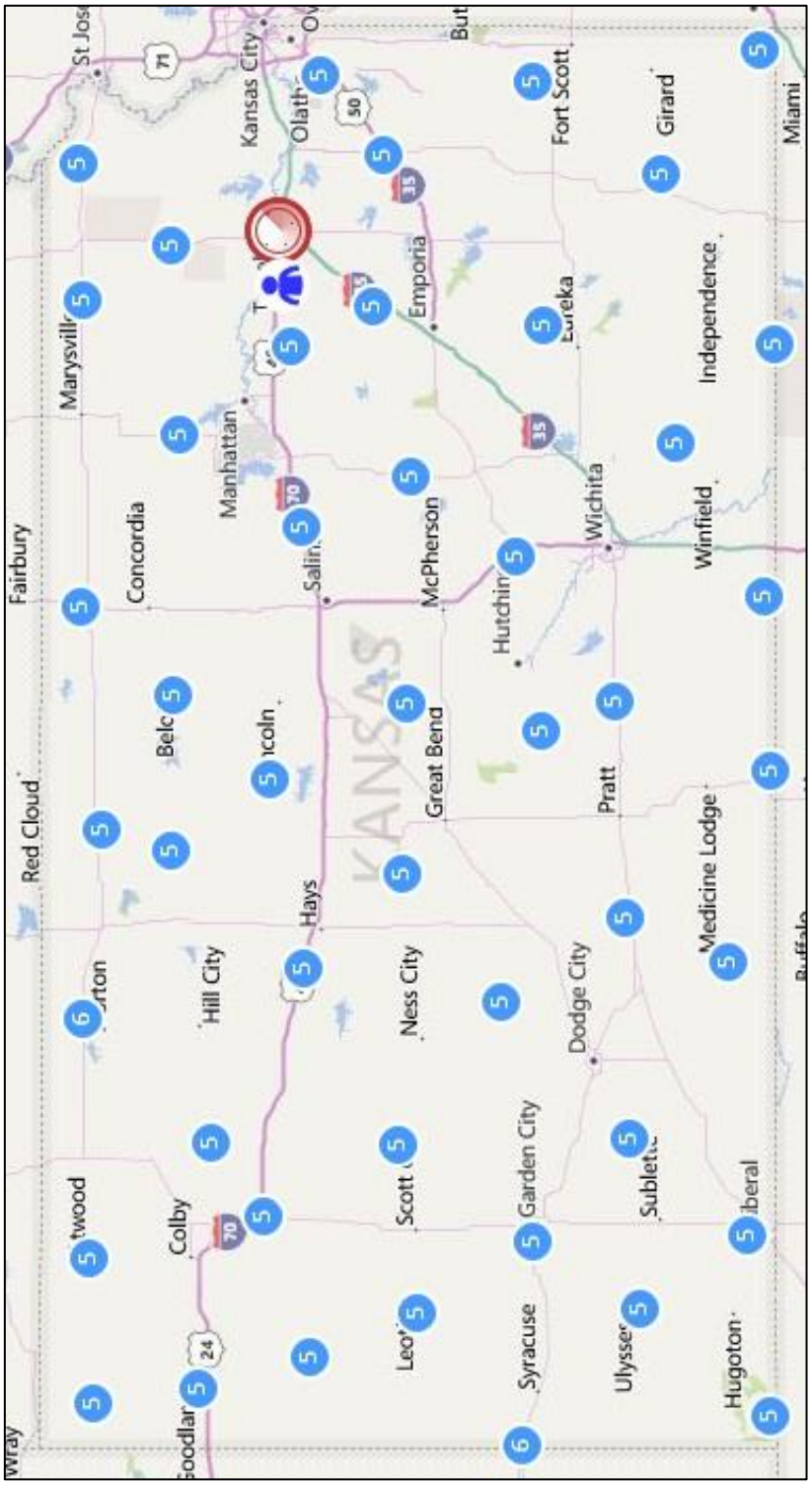
Additional Information can be obtained by contacting the Kansas Radiation Control Program (http://www.kdheks.gov/radiation/index.html).

More information is available about the Kansas Environmental Public Health Tracking Program on their website https://keap.kdhe.state.ks.us/Ephtm/ or by email kdhe.ksepht@ks.gov

Appendix 1: Kansas Sample Locations



Appendix 2: RadResponder Sampling Location Map



Appendix 3: Gamma Exposure Rate Data Table

Collected	Value	Units	Height	Unit	Description	Meter	Latitude	Longitude
7/9/2015 14:58	13	uR/hr	3	foot	Abilene, KS	Ludlum 19 - SN#: 120905	38.949102	-97.228049
7/9/2015 15:02	15	uR/hr	3	foot	Abilene, KS	Victoreen 451P - SN#: 4935	38.949102	-97.228049
7/30/2015 11:22	11	uR/hr	3	foot	Admire, KS	Ludlum 19 - SN#: 120905	38.65853	-96.06987
7/30/2015 11:54	10	uR/hr	3	foot	Admire, KS	Victoreen 451P - SN#: 4935	38.65853	-96.06987
7/7/2015 14:32	9	uR/hr	3	foot	Alma, KS	Ludlum 19 - SN#: 120905	38.99269	-96.274662
7/7/2015 15:25	17	uR/hr	3	foot	Alma, KS	Victoreen 451P - SN#: 4935	38.99269	-96.27466
7/27/2015 13:43	14	uR/hr	3	foot	Alton, KS	Ludlum 19 - SN#: 120905	39.480951	-98.918404
7/27/2015 13:47	16	uR/hr	3	foot	Alton, KS	Victoreen 451P - SN#: 4935	39.480951	-98.918404
7/16/2015 17:06	11	uR/hr	3	foot	Atlanta, KS	Ludlum 19 - SN#: 120905	37.41765	-96.78645
7/16/2015 17:11	17	uR/hr	3	foot	Atlanta, KS	Victoreen 451P - SN#: 4935	37.41765	-96.78645
7/29/2015 10:52	12	uR/hr	3	foot	Atwood, KS	Ludlum 19 - SN#: 120905	39.810078	-101.046863
7/29/2015 10:54	13	uR/hr	3	foot	Atwood, KS	Victoreen 451P - SN#: 4935	39.810078	-101.046863
7/14/2015 12:22	10	uR/hr	3	foot	Baxter Springs, KS	Ludlum 19 - SN#: 120905	37.06755	-94.726873
7/14/2015 12:30	12	uR/hr	3	foot	Baxter Springs, KS	Victoreen 451P - SN#: 4935	37.06751	-94.726825
7/10/2015 11:36	18	uR/hr	3	foot	Belleville, KS	Victoreen 451P - SN#: 4935	39.841595	-97.646533
7/10/2015 11:37	13	uR/hr	3	foot	Belleville, KS	Ludlum 19 - SN#: 120905	39.841595	-97.646533
7/13/2015 12:57	11	uR/hr	3	foot	Beloit, KS	Ludlum 19 - SN#: 120905	39.47425	-98.09769

7/13/2015 13:00	17	uR/hr	3	foot	Beloit, KS	Victoreen 451P - SN#: 4935	39.47425	-98.09769
7/20/2015 12:24	15	uR/hr	3	foot	Caldwell, KS	Ludlum 19 - SN#: 120905	37.04551	-97.582468
7/20/2015 12:27	14	uR/hr	3	foot	Caldwell, KS	Victoreen 451P - SN#: 4935	37.04551	-97.582468
7/22/2015 13:15	16	uR/hr	3	foot	Coolidge, KS	Ludlum 19 - SN#: 120905	38.04387	-102.02745
7/22/2015 13:19	17	uR/hr	3	foot	Coolidge, KS	Victoreen 451P - SN#: 4935	38.04387	-102.02745
7/23/2015 1:04	12	uR/hr	3	foot	Dighton, KS	Ludlum 19 - SN#: 120905	38.55455	-100.45889
7/23/2015 1:08	13	uR/hr	3	foot	Dighton, KS	Victoreen 451P - SN#: 4935	38.55455	-100.45889
7/16/2015 16:56	10	uR/hr	3	foot	Elgin, KS	Ludlum 19 - SN#: 120905	37.00667	-96.2663
7/16/2015 17:01	13	uR/hr	3	foot	Elgin, KS	Victoreen 451P - SN#: 4935	37.00667	-96.2663
7/21/2015 14:12	7	uR/hr	3	foot	Elkhart, KS	Ludlum 19 - SN#: 120905	37.021848	-101.874227
7/21/2015 14:15	12	uR/hr	3	foot	Elkhart, KS	Victoreen 451P - SN#: 4935	37.021848	-101.874227
7/30/2015 10:35	12	uR/hr	3	foot	Ellis, KS	Ludlum 19 - SN#: 120905	38.94276	-99.53575
7/30/2015 11:04	12	uR/hr	3	foot	Ellis, KS	Victoreen 451P - SN#: 4935	38.94276	-99.53575
7/14/2015 14:34	9	uR/hr	3	foot	Galesburg, KS	Ludlum 19 - SN#: 120905	37.471181	-95.379077
7/14/2015 14:42	10	uR/hr	3	foot	Galesburg, KS	Victoreen 451P - SN#: 4935	37.471181	-95.379077
7/22/2015 10:29	13	uR/hr	3	foot	Garden City, KS	Ludlum 19 - SN#: 120905	38.003683	-100.957136
7/22/2015 10:33	15	uR/hr	3	foot	Garden City, KS	Victoreen 451P - SN#: 4935	38.003683	-100.957136
7/15/2015 11:42	13	uR/hr	3	foot	Geneseo, KS	Ludlum 19 - SN#: 120905	38.522127	-98.145845

7/15/2015 11:51	12	uR/hr	3	foot	Geneseo, KS	Victoreen 451P - SN#: 4935	38.522127	-98.145845
7/28/2015 19:53	14	uR/hr	3	foot	Goodland, KS	Ludlum 19 - SN#: 120905	39.3663	-101.72576
7/28/2015 19:58	15	uR/hr	3	foot	Goodland, KS	Victoreen 451P - SN#: 4935	39.3663	-101.72576
7/21/2015 1:15	13	uR/hr	3	foot	Greensburg, KS	Ludlum 19 - SN#: 120905	37.62006	-99.26744
7/21/2015 1:20	14	uR/hr	3	foot	Greensburg, KS	Victoreen 451P - SN#: 4935	37.62006	-99.26744
7/9/2015 11:00	10	uR/hr	3	foot	Hamilton, KS	Ludlum 19 - SN#: 120905	37.96115	-96.17345
7/9/2015 11:05	17	uR/hr	3	foot	Hamilton, KS	Victoreen 451P - SN#: 4935	37.96115	-96.17345
7/23/2015 10:02	14	uR/hr	3	foot	Hanston, KS	Ludlum 19 - SN#: 120905	38.13156	-99.707377
7/23/2015 10:07	15	uR/hr	3	foot	Hanston, KS	Victoreen 451P - SN#: 4935	38.13156	-99.707377
7/7/2015 9:50	10	uR/hr	3	foot	Highland, KS	Ludlum 19 - SN#: 120905	39.849488	-95.332393
7/7/2015 10:13	15	uR/hr	3	foot	Highland, KS	Victoreen 451P - SN#: 4935	39.847196	-95.323486
7/6/2015 13:22	10	uR/hr	3	foot	Holton, KS	Ludlum 19 - SN#: 120905	39.475129	-95.757157
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7/29/2015 12:28	15	uR/hr	3	foot	Hoxie, KS	Victoreen 451P - SN#: 4935	39.321337	-100.443251
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7/21/2015 12:51	13	uR/hr	3	foot	Liberal, KS	Victoreen 451P - SN#: 4935	37.11234	-100.921648
7/9/2015 15:17	12	uR/hr	3	foot	Lincolnville, KS	Ludlum 19 - SN#: 120905	38.50797	-96.95581
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7/17/2015 11:22	11	uR/hr	3	foot	Lucas, KS	Ludlum 19 - SN#: 120905	39.075298	-98.540538
7/17/2015 11:27	15	uR/hr	3	foot	Lucas, KS	Victoreen 451P - SN#: 4935	39.07539	-98.540638
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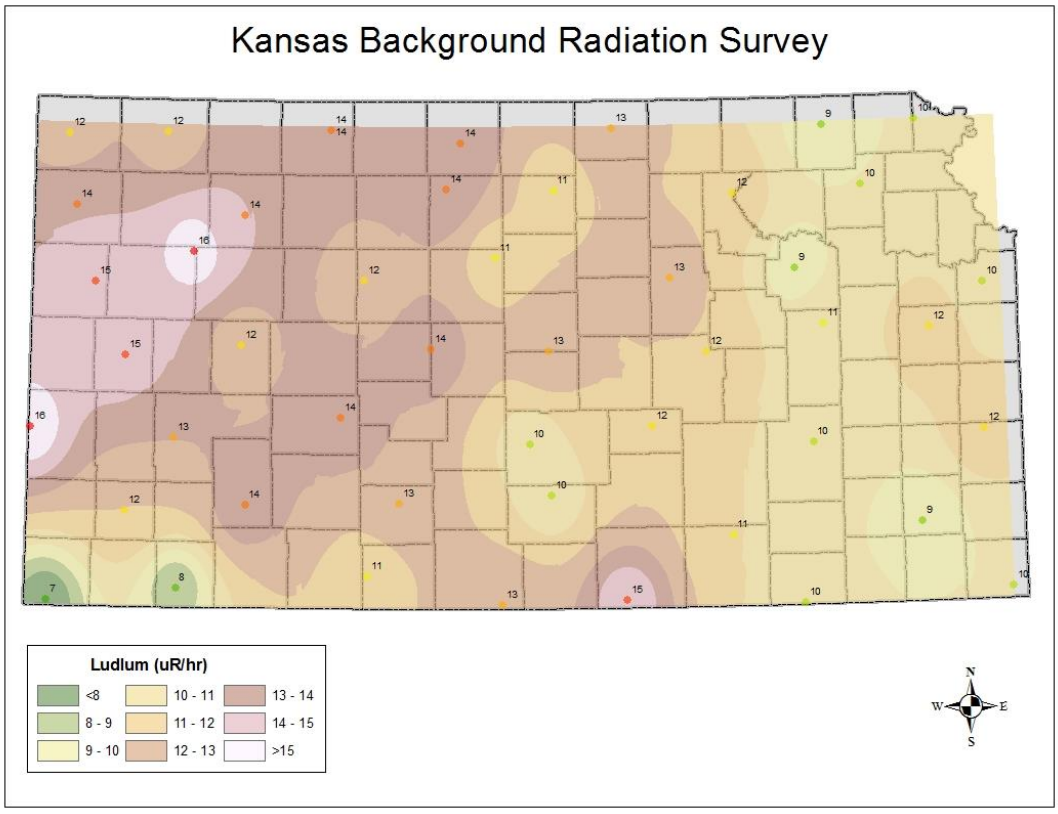
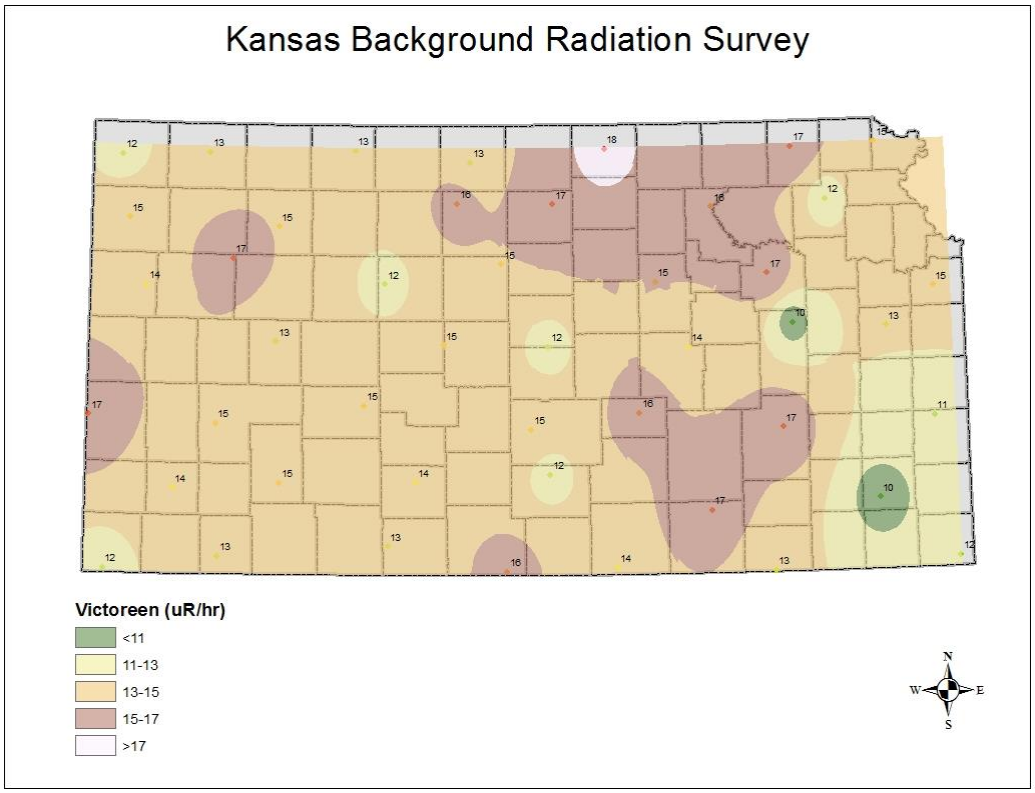
7/8/2015 16:04	11	uR/hr	3	foot	Mapleton, KS	Victoreen 451P - SN#: 4935	38.00788	-94.89707
7/21/2015 16:53	14	uR/hr	3	foot	Montezuma, KS	Ludlum 19 - SN#: 120905	37.607198	-100.415889
7/21/2015 16:56	15	uR/hr	3	foot	Montezuma, KS	Victoreen 451P - SN#: 4935	37.607198	-100.415889
7/15/2015 15:09	12	uR/hr	3	foot	Newton, KS	Ludlum 19 - SN#: 120905	38.072118	-97.379171
7/15/2015 15:12	16	uR/hr	3	foot	Newton, KS	Victoreen 451P - SN#: 4935	38.072118	-97.379171
7/28/2015 0:43	14	uR/hr	3	foot	Norton, KS	Ludlum 19 - SN#: 120905	39.83354	-99.79534
7/28/2015 0:48	13	uR/hr	3	foot	Norton, KS	Victoreen 451P - SN#: 4935	39.83354	-99.79534
7/28/2015 0:43	14	uR/hr	3	foot	Norton, KS	Ludlum 19 - SN#: 120905	39.83354	-99.79534
7/28/2015 19:14	16	uR/hr	3	foot	Oakley, KS	Ludlum 19 - SN#: 120905	39.10491	-100.83267

7/28/2015 19:20	17	uR/hr	3	foot	Oakley, KS	Victoreen 451P - SN#: 4935	39.10491	-100.83267
7/8/2015 9:37	10	uR/hr	3	foot	Olathe, KS	Ludlum 19 - SN#: 120905	38.871207	-94.862691
7/8/2015 10:27	15	uR/hr	3	foot	Olathe, KS	Victoreen 451P - SN#: 4935	38.87121	-94.86269
7/23/2015 11:39	14	uR/hr	3	foot	Otis, KS	Ludlum 19 - SN#: 120905	38.535688	-99.032938
7/23/2015 11:42	15	uR/hr	3	foot	Otis, KS	Victoreen 451P - SN#: 4935	38.535688	-99.032938
7/8/2015 11:18	12	uR/hr	3	foot	Ottawa, KS	Ludlum 19 - SN#: 120905	38.617325	-95.27898
7/8/2015 11:22	13	uR/hr	3	foot	Ottawa, KS	Victoreen 451P - SN#: 4935	38.617325	-95.27898
7/15/2015 15:14	10	uR/hr	3	foot	Plevna, KS	Ludlum 19 - SN#: 120905	37.9701	-98.29412
7/15/2015 15:19	15	uR/hr	3	foot	Plevna, KS	Victoreen 451P - SN#: 4935	37.9701	-98.29412
7/21/2015 10:23	11	uR/hr	3	foot	Protection, KS	Ludlum 19 - SN#: 120905	37.192372	-99.500976
7/21/2015 10:27	13	uR/hr	3	foot	Protection, KS	Victoreen 451P - SN#: 4935	37.192372	-99.500976
7/10/2015 11:44	12	uR/hr	3	foot	Randolph, KS	Ludlum 19 - SN#: 120905	39.4432	-96.7387
7/10/2015 11:49	16	uR/hr	3	foot	Randolph, KS	Victoreen 451P - SN#: 4935	39.4432	-96.7387
7/7/2015 11:50	9	uR/hr	3	foot	Seneca, KS	Ludlum 19 - SN#: 120905	39.83174	-96.04267
7/7/2015 11:53	17	uR/hr	3	foot	Seneca, KS	Victoreen 451P - SN#: 4935	39.83174	-96.04267
7/27/2015 14:44	14	uR/hr	3	foot	Smith Center, KS	Ludlum 19 - SN#: 120905	39.756311	-98.804565
7/27/2015 14:47	13	uR/hr	3	foot	Smith Center, KS	Victoreen 451P - SN#: 4935	39.756311	-98.804565
7/28/2015 20:09	12	uR/hr	3	foot	St. Francis, KS	Ludlum 19 - SN#: 120905	39.78947	-101.80042

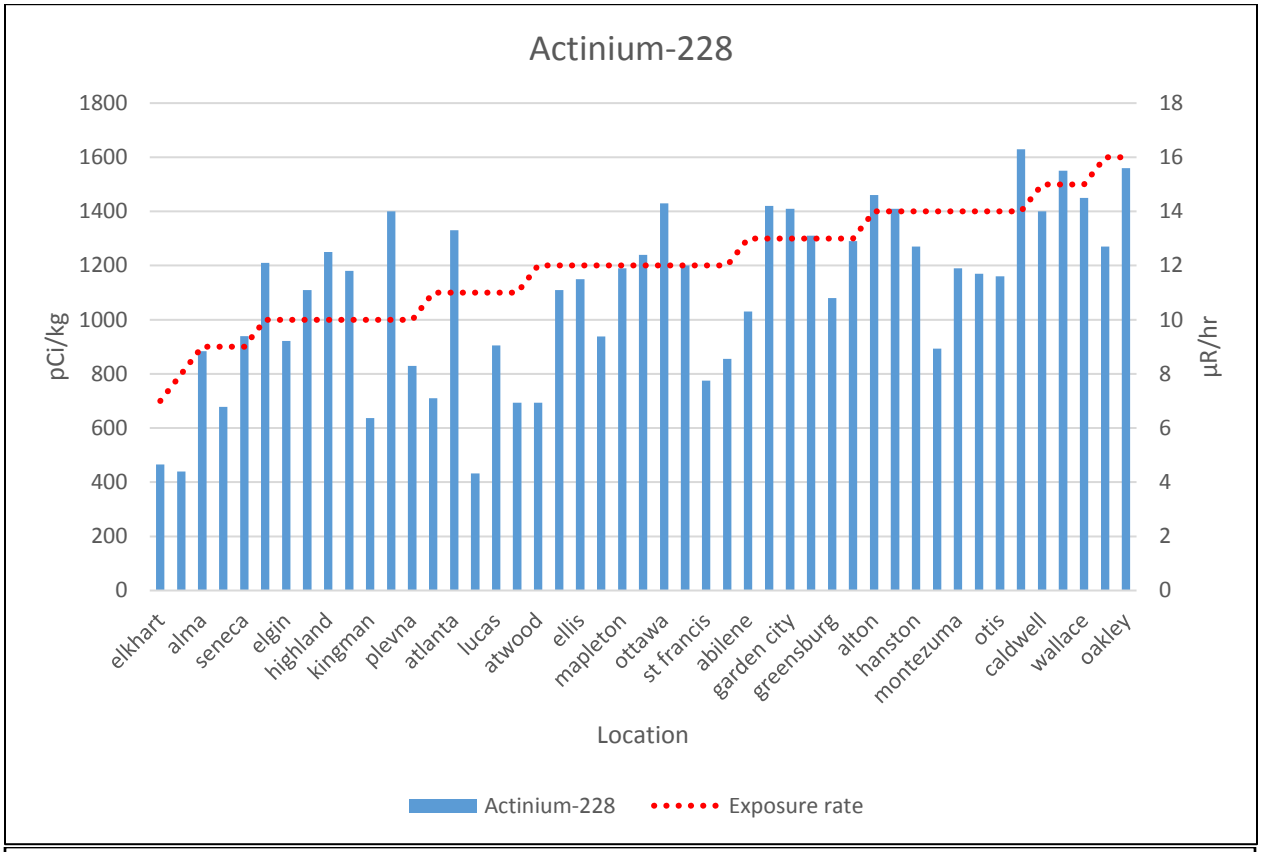
7/28/2015 20:16	12	uR/hr	3	foot	St. Francis, KS	Victoreen 451P - SN#: 4935	39.78947	-101.80042
7/21/2015 15:43	12	uR/hr	3	foot	Ulysses, KS	Ludlum 19 - SN#: 120905	37.564265	-101.308239
7/21/2015 15:45	14	uR/hr	3	foot	Ulysses, KS	Victoreen 451P - SN#: 4935	37.564265	-101.308239
7/28/2015 19:25	15	uR/hr	3	foot	Wallace, KS	Ludlum 19 - SN#: 120905	38.91737	-101.56821
7/28/2015 19:33	14	uR/hr	3	foot	Wallace, KS	Victoreen 451P - SN#: 4935	38.91737	-101.56821

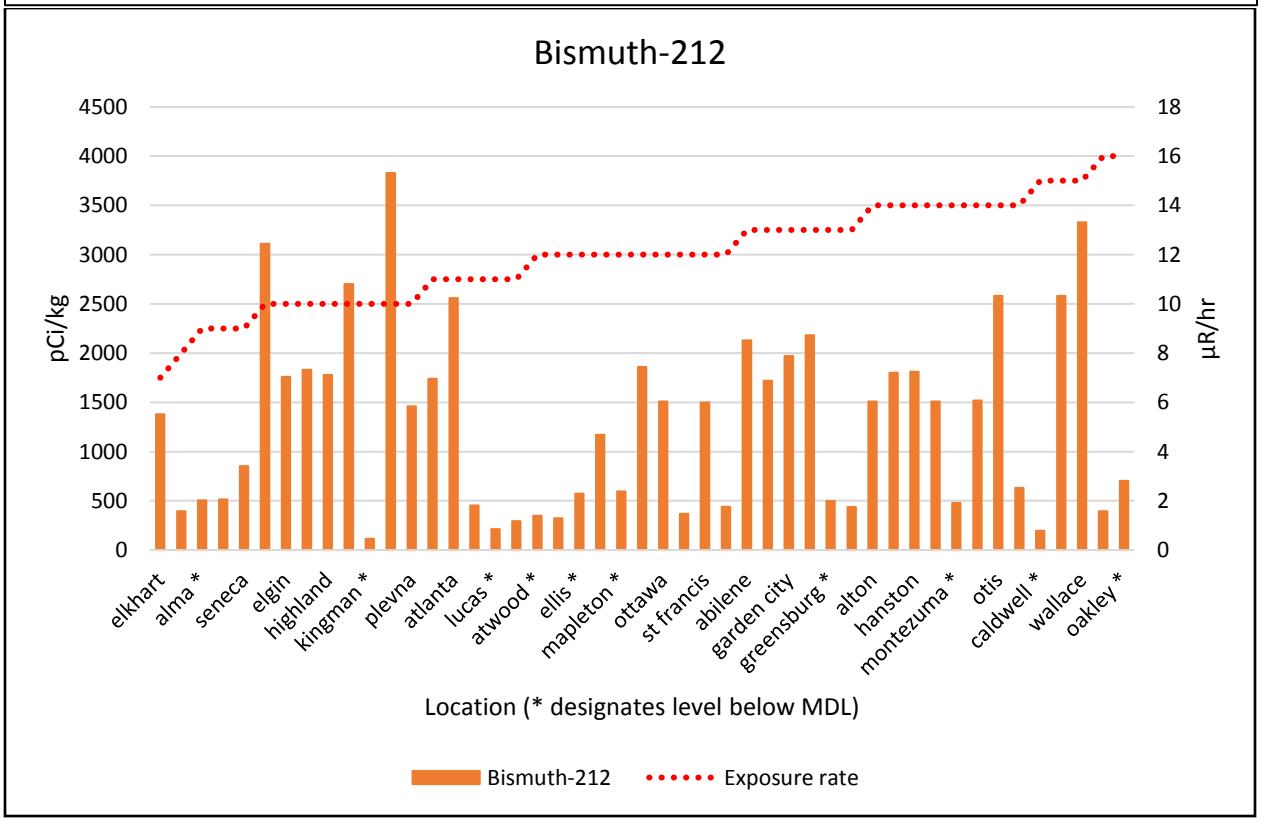
Appendix 4: Gamma Exposure Rate Maps

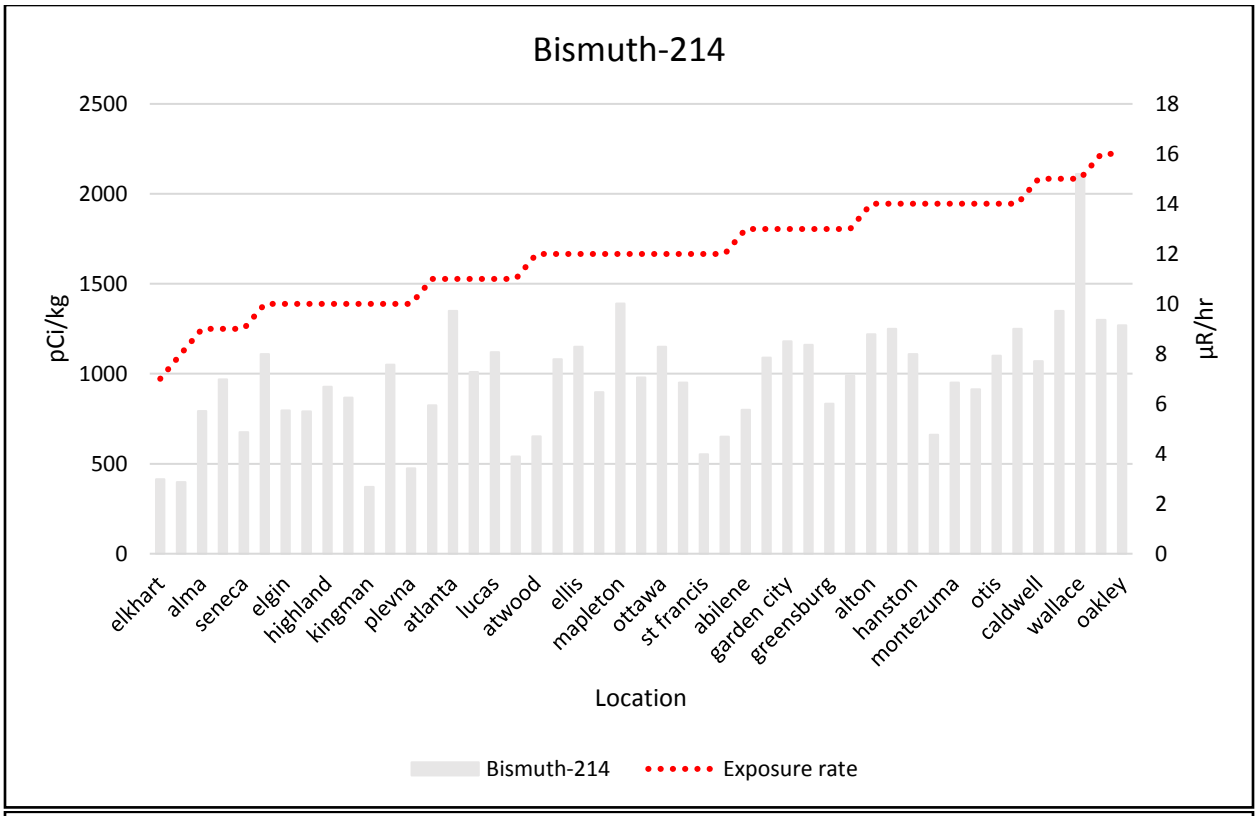


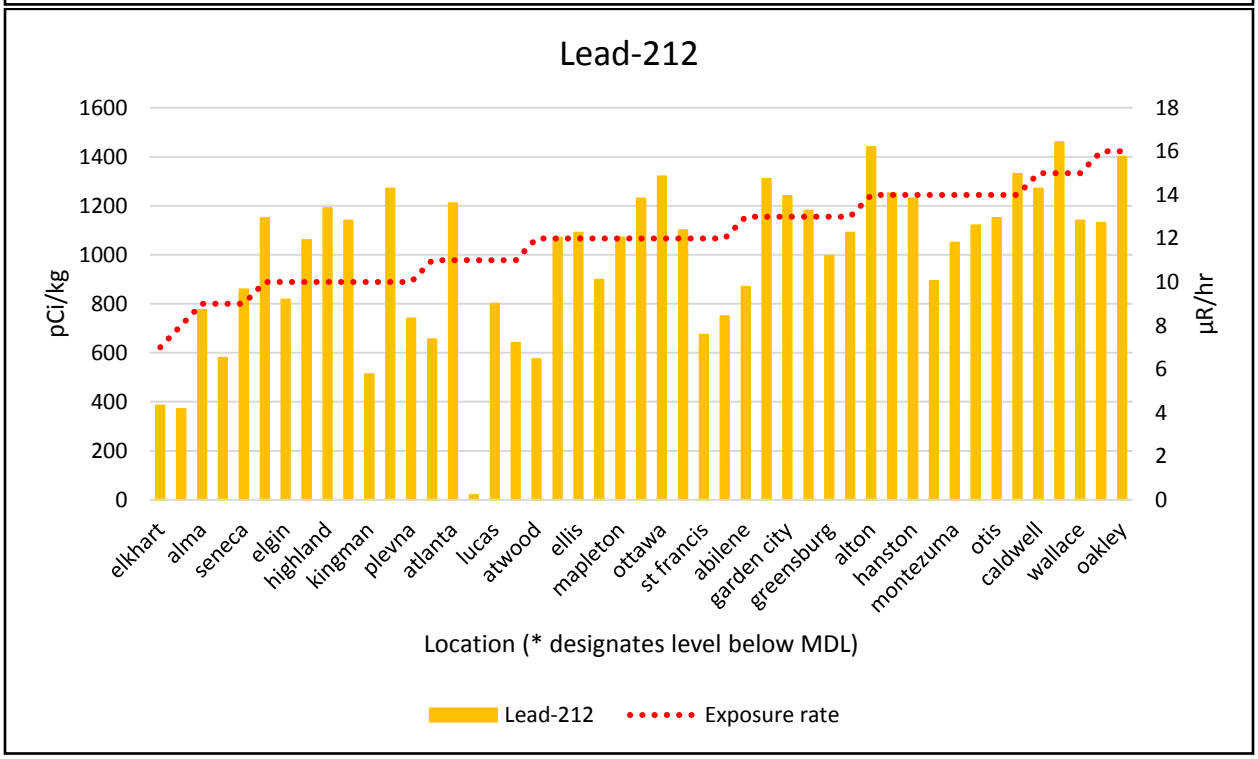


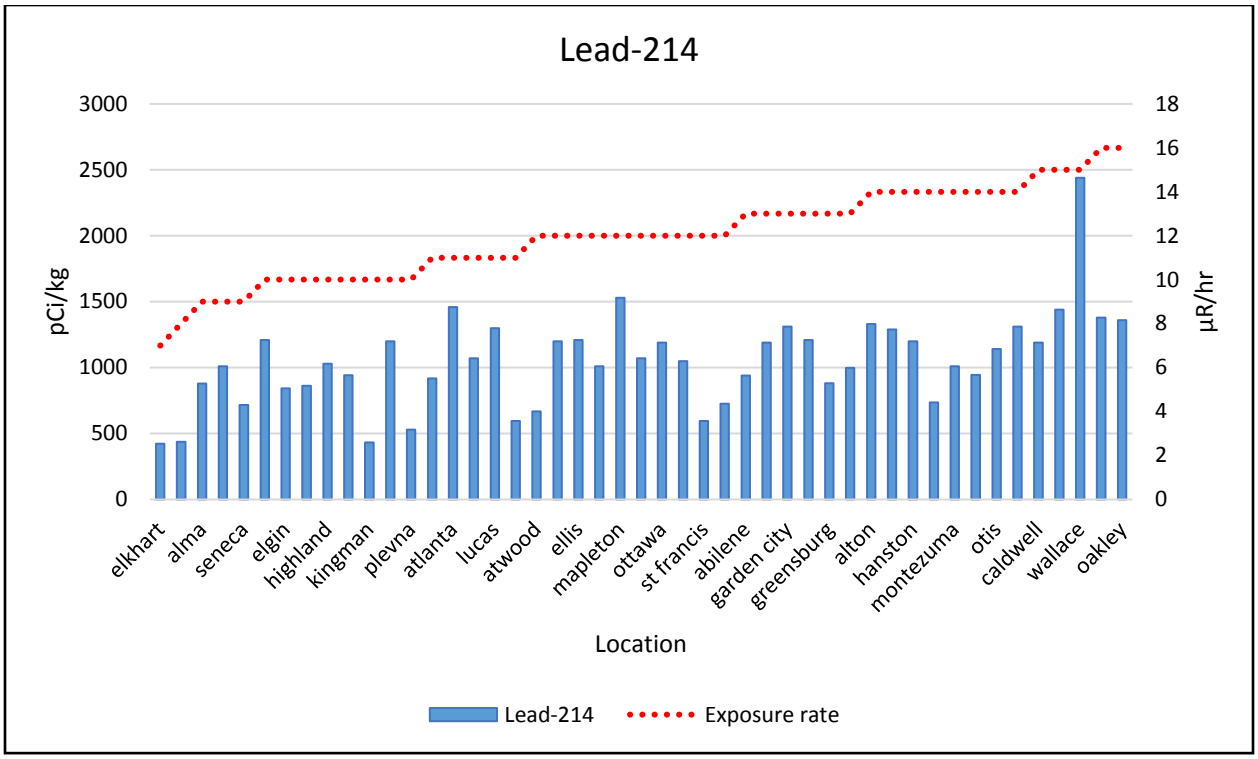
Appendix 5: Radionuclide Activities with Exposure Rate

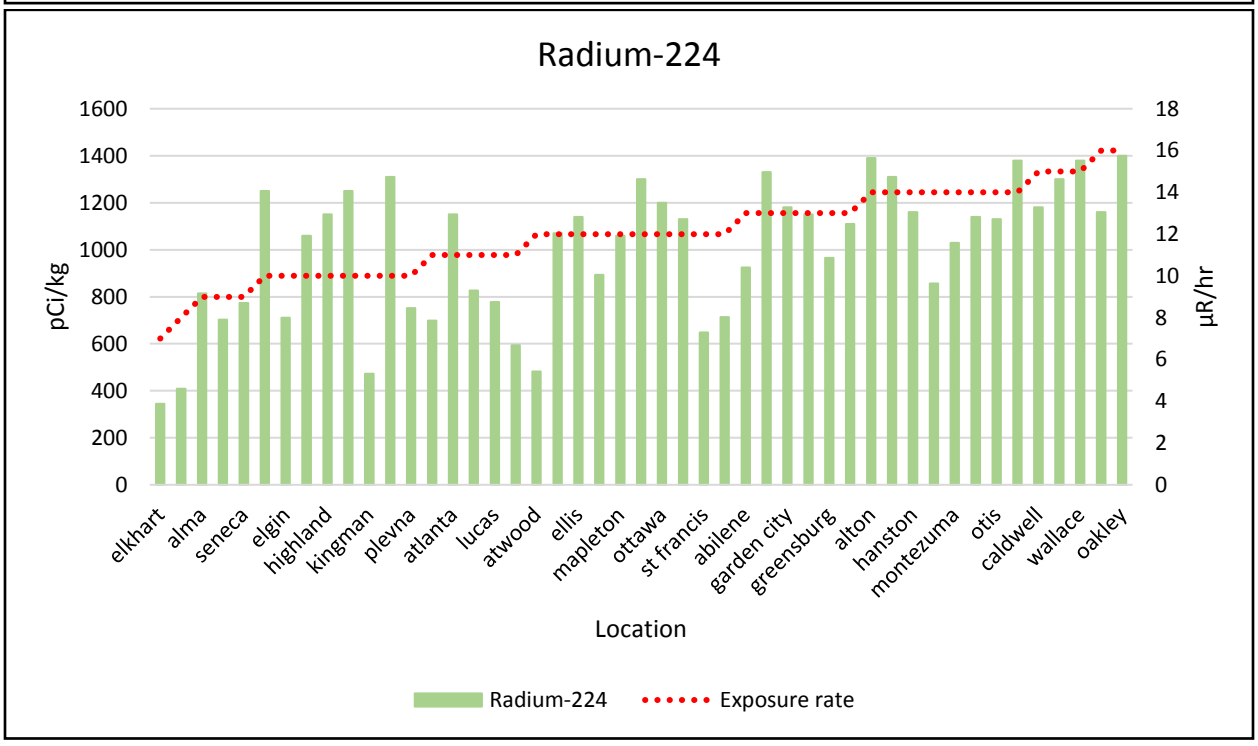


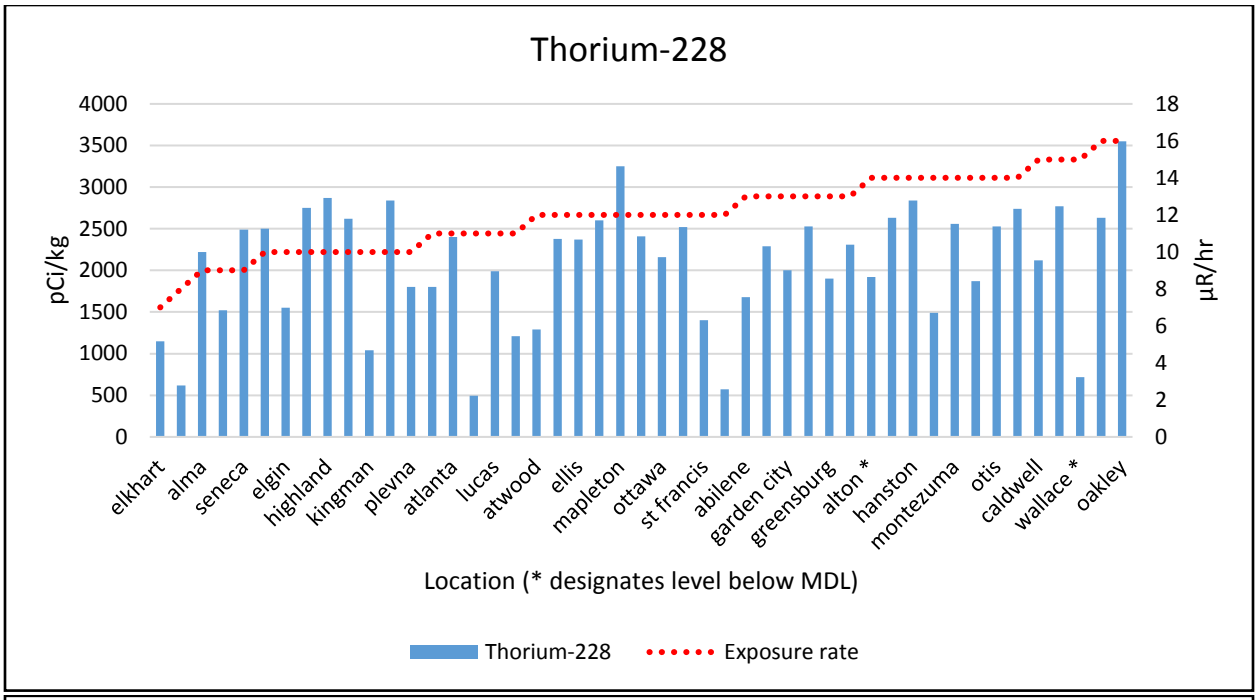


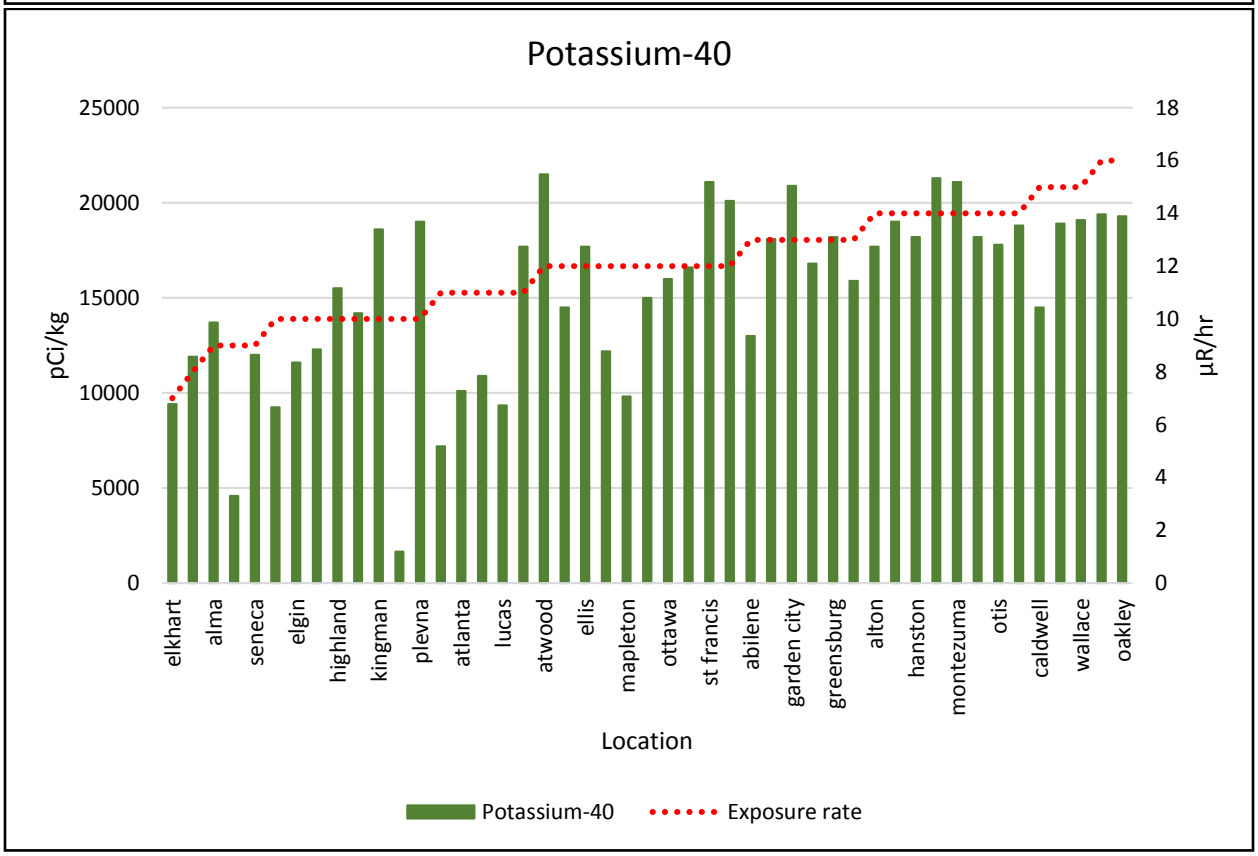

Bismuth-214
2500
2000
1500
1000
500
0
pCi/kg
18
16
14
12
10
8
6
4
2
0
µR/hr
elkhart
alma
seneca
elgin
highland
kingman
plevna
atlanta
lucas
atwood
ellis
mapleton
ottawa
st francis
abilene
garden city
greensburg
alton
hanston
montezuma
otis
caldwell
wallace
oakley
Location
Bismuth-214
Exposure rate

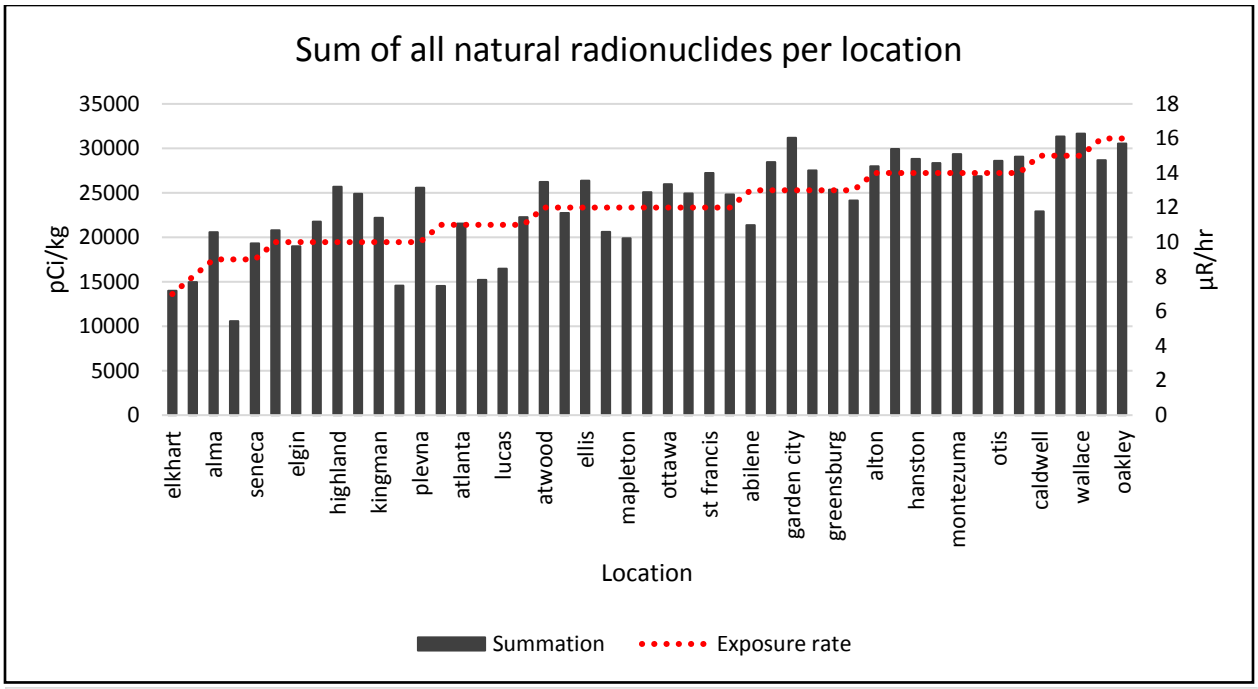

Lead-212
1600
1400
1200
1000
800
600
400
200
0
pCi/kg
18
16
14
12
10
8
6
4
2
0
µR/hr
elkhart
alma
seneca
elgin
highland
kingman
plevna
atlanta
lucas
atwood
ellis
mapleton
ottawa
st francis
abilene
garden city
greensburg
alton
hanston
montezuma
otis
caldwell
wallace
oakley
Location (* designates level below MDL)
Lead-212
Exposure rate

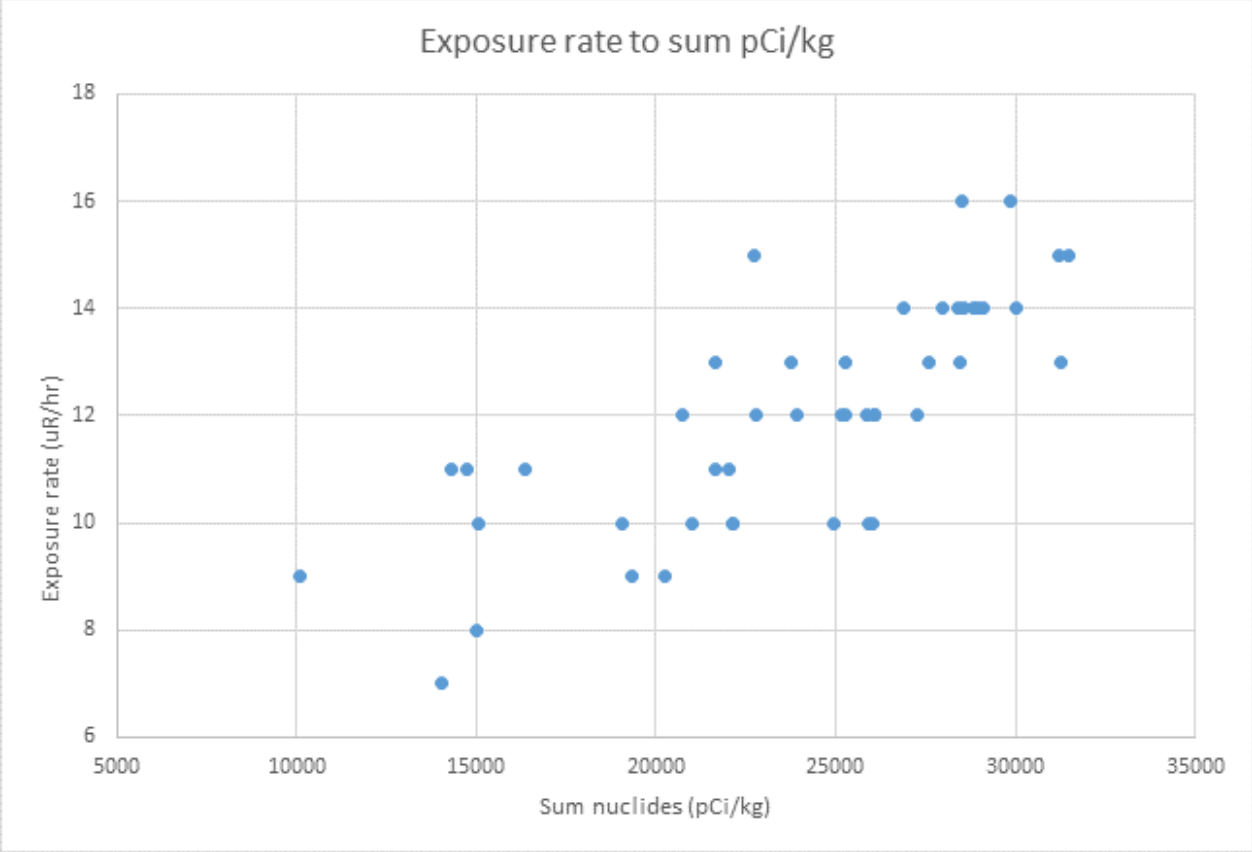

Lead-214
3000
2500
2000
1500
1000
500
0
pCi/kg
18
16
14
12
10
8
6
4
2
0
µR/hr
elkhart
alma
seneca
elgin
highland
kingman
plevna
atlanta
lucas
atwood
ellis
mapleton
ottawa
st francis
abilene
garden city
greensburg
alton
hanston
montezuma
otis
caldwell
wallace
oakley
Location
Lead-214
Exposure rate


Radium-224
1600
1400
1200
1000
800
600
400
200
0
pCi/kg
18
16
14
12
10
8
6
4
2
0
µR/hr
elkhart
alma
seneca
elgin
highland
kingman
plevna
atlanta
lucas
atwood
ellis
mapleton
ottawa
st francis
abilene
garden city
greensburg
alton
hanston
montezuma
otis
caldwell
wallace
oakley
Location
Radium-224
Exposure rate


Thorium-228
pCi/kg
µR/hr
4000
3500
3000
2500
2000
1500
1000
500
0
18
16
14
12
10
8
6
4
2
0
elkhart
alma
seneca
elgin
highland
kingman
plevna
atlanta
lucas
atwood
ellis
mapleton
ottawa
st francis
abilene
garden city
greensburg
alton *
hanston
montezuma
otis
caldwell
wallace *
oakley
Location (* designates level below MDL)
Thorium-228
Exposure rate

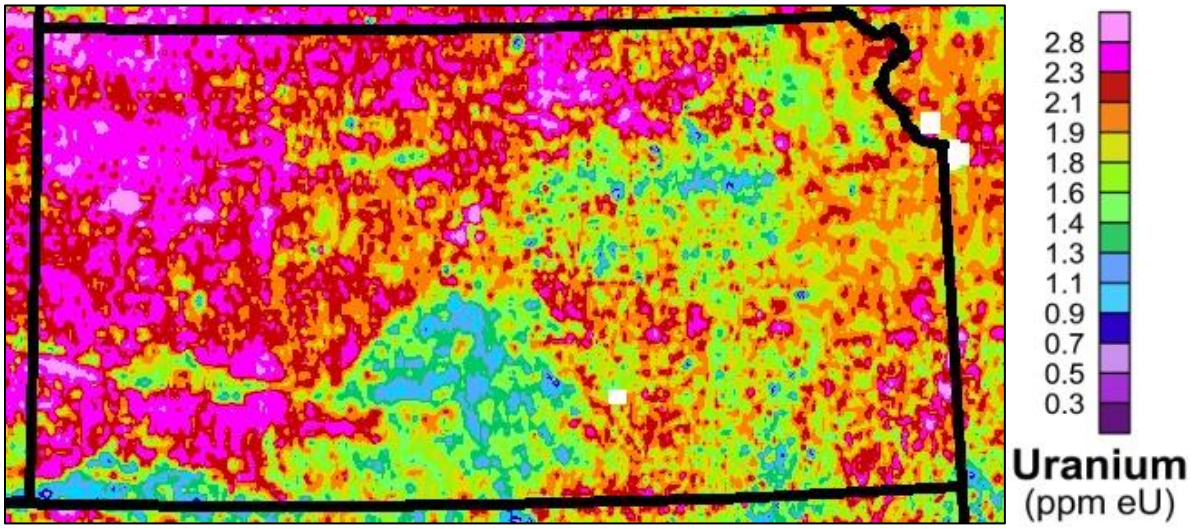

Potassium-40
pCi/kg
µR/hr
25000
20000
15000
10000
5000
0
18
16
14
12
10
8
6
4
2
0
elkhart
alma
seneca
elgin
highland
kingman
plevna
atlanta
lucas
atwood
ellis
mapleton
ottawa
st francis
abilene
garden city
greensburg
alton
hanston
montezuma
otis
caldwell
wallace
oakley
Location
Potassium-40
Exposure rate


Sum of all natural radionuclides per location
pCi/kg
µR/hr
35000
30000
25000
20000
15000
10000
5000
0
18
16
14
12
10
8
6
4
2
0
elkhart
alma
seneca
elgin
highland
kingman
plevna
atlanta
lucas
atwood
ellis
mapleton
ottawa
st francis
abilene
garden city
greensburg
alton
hanston
montezuma
otis
caldwell
wallace
oakley
Location
Summation
Exposure rate

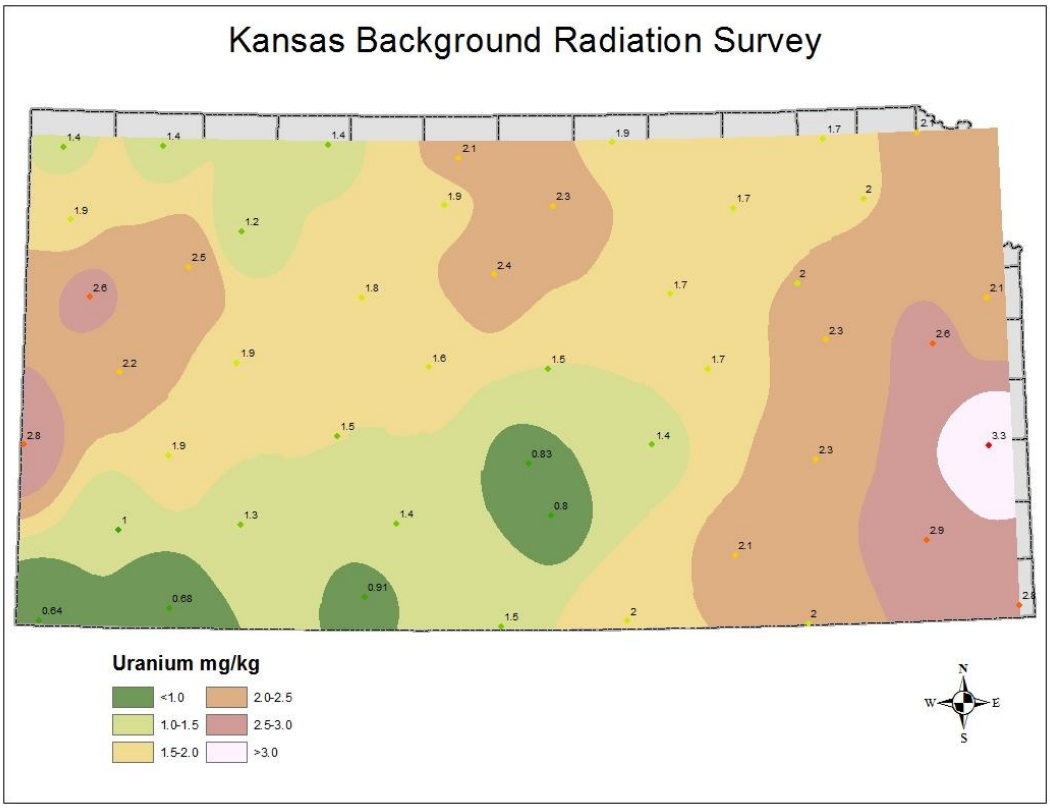

Exposure rate to sum pCi/kg
Exposure rate (uR/hr)
18
16
14
12
10
8
6
5000
10000
15000
20000
25000
30000
35000
Sum nuclides (pCi/kg)

Appendix 6: Uranium Concentration Maps

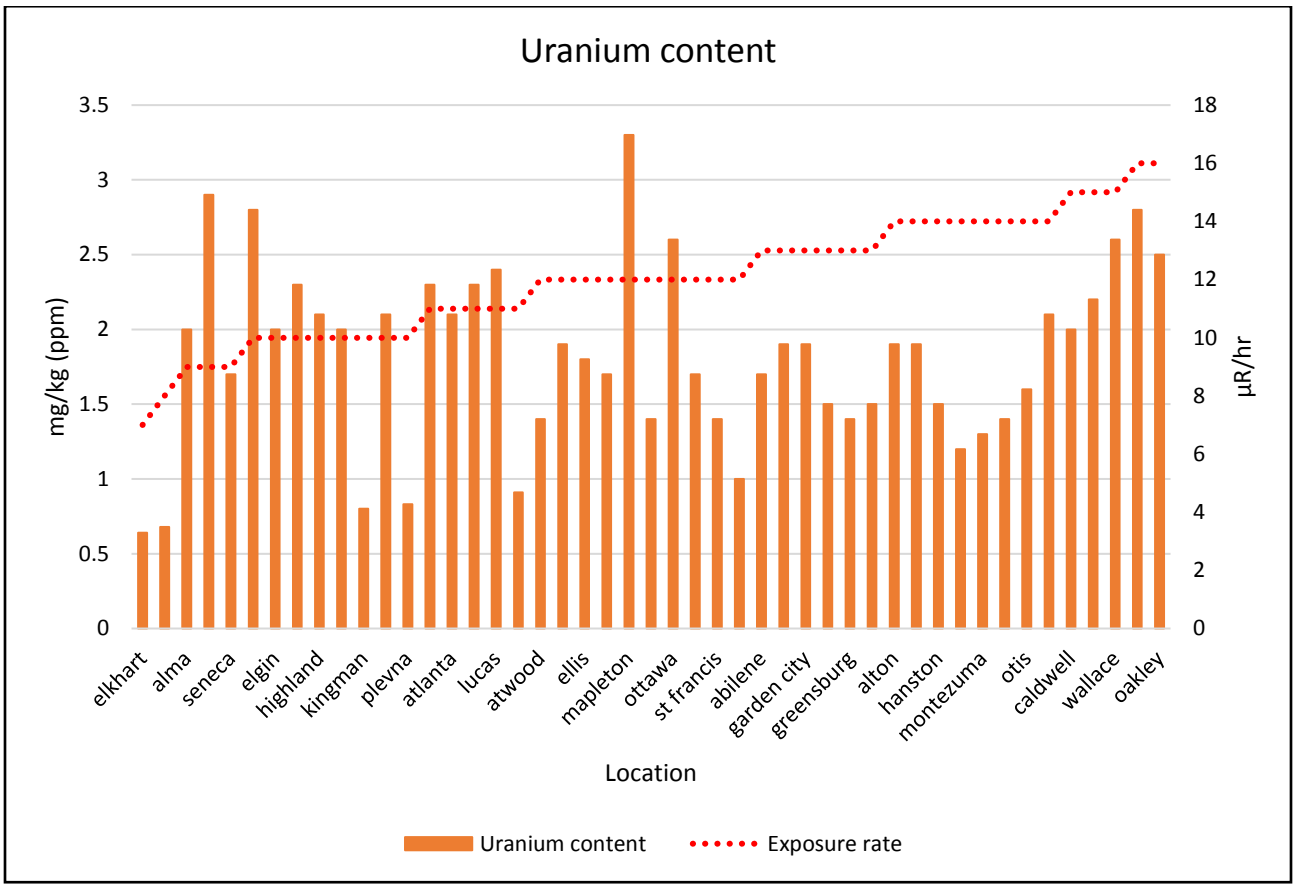
USGS OF-2005-1413



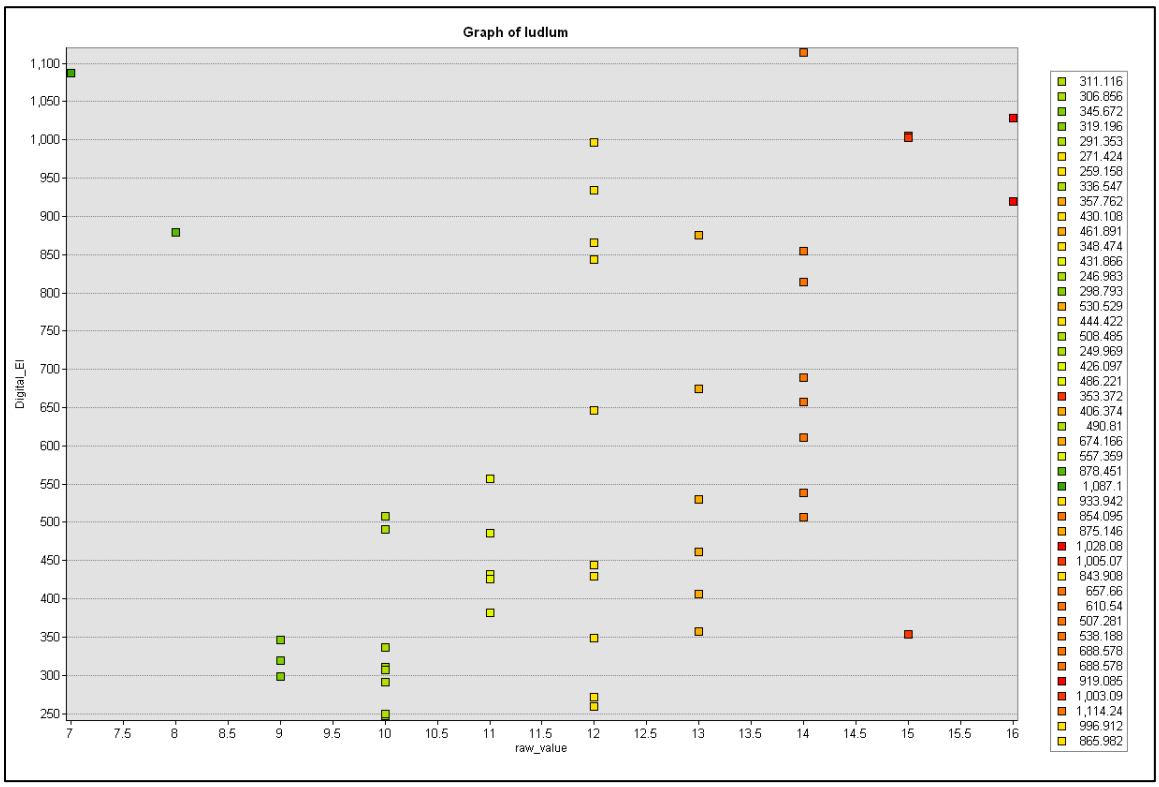
Kansas uranium concentration

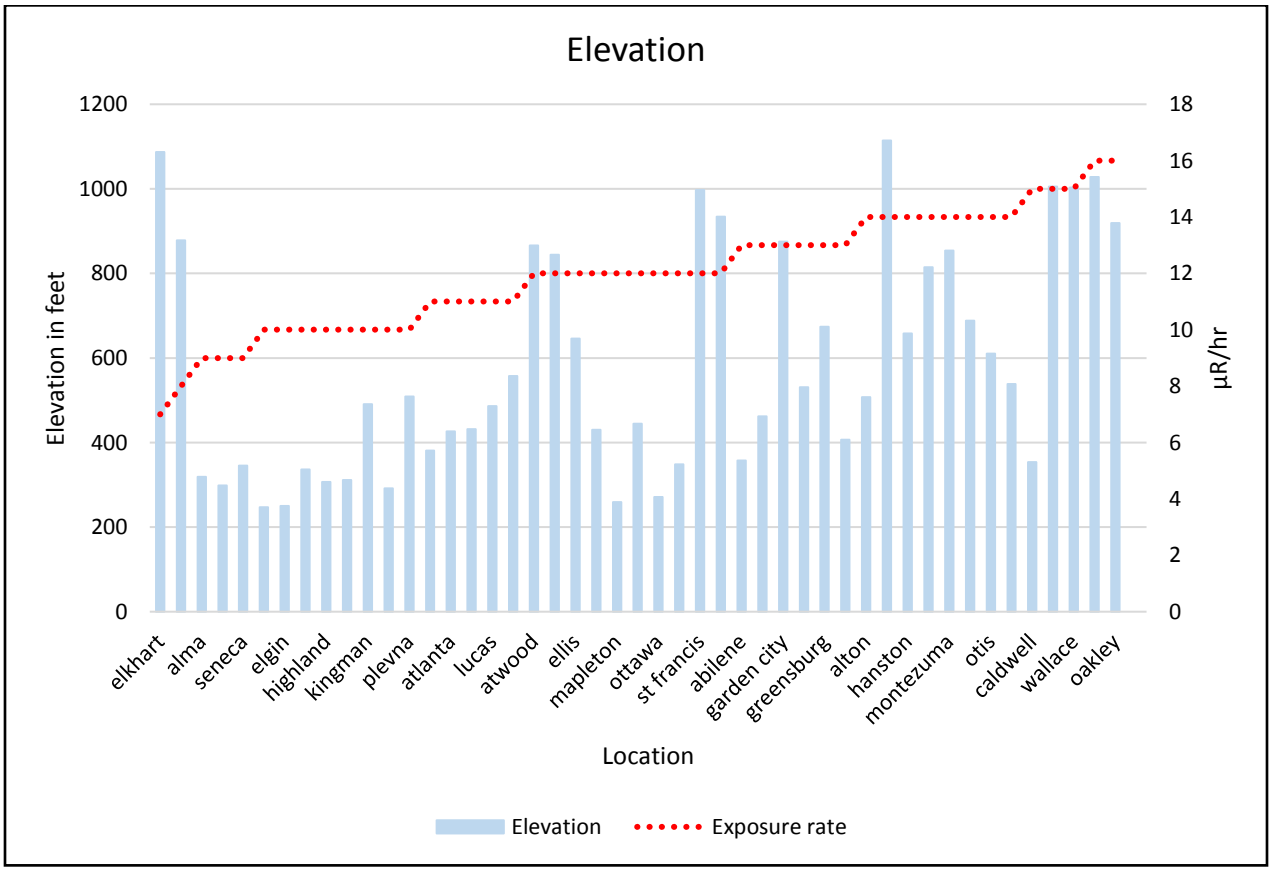


Appendix 7: Uranium Concentration with Exposure Rate

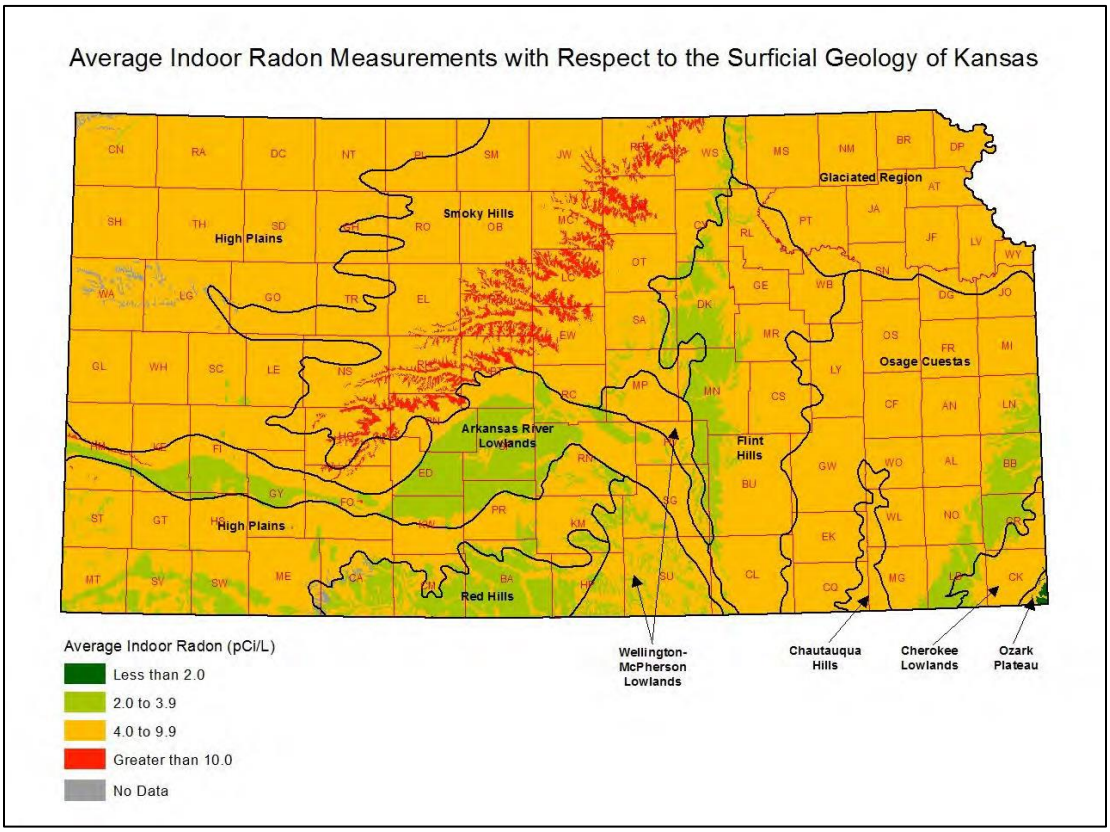


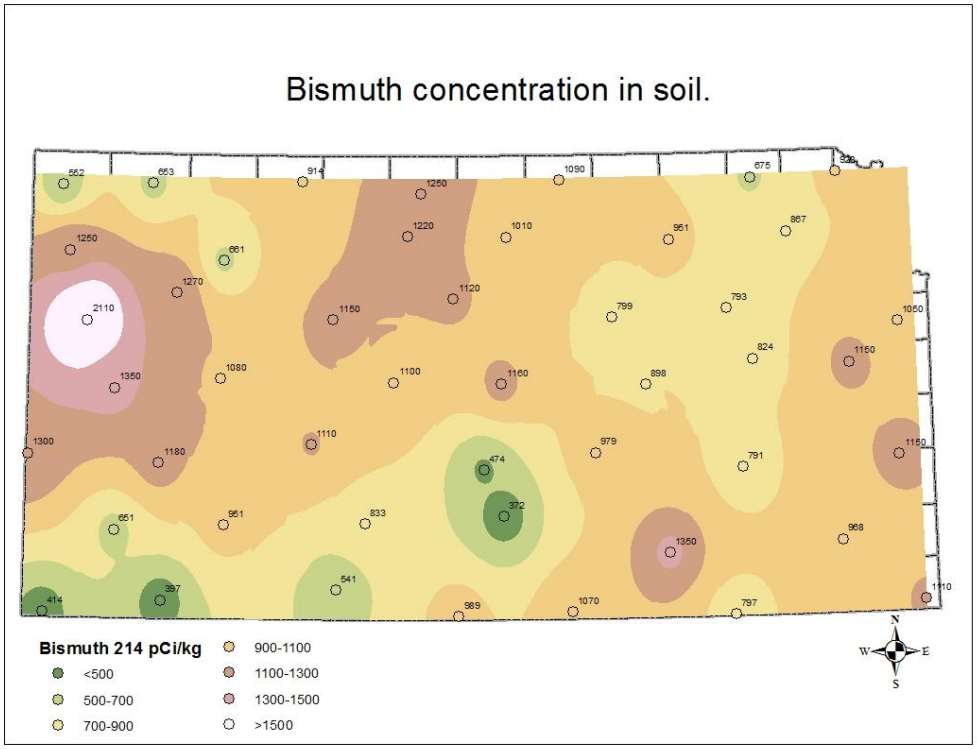
Appendix 8: Effect of Elevation on Exposure Rates

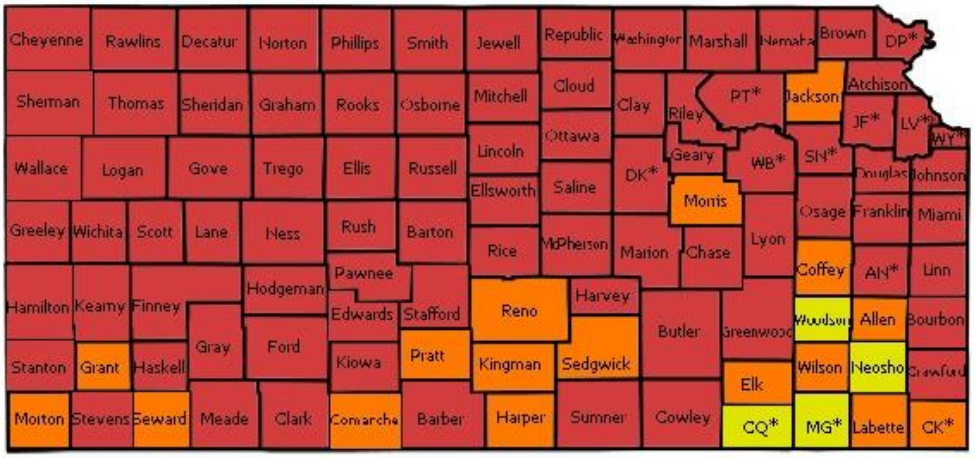




Appendix 9: Kansas Radon Maps







Average Radon Level = 5.1 pCi/L
Maximum Reported Radon Level = 1,121.6
Total Number of Measurements = 73,959
Total Measurements 4 pCi/L or greater = 31,539
Total Measurements 20 pCi/L or greater = 1,957

Legend

RADON

- 0.0 - 1.9 pCi/L
- 2.0 - 3.9 pCi/L
- 4.0 pCi/L or more