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1. NUCLEAR HISTORY

Nuclear chemistry is a relatively new field of atomic study that began in the late 1800's with the discovery of X-rays by Wilhelm Roentgen and the subsequent discovery of natural radiation in 1896 by Henri Becquerel("Wilhelm Conrad Röntgen – Biographical" & "Henri Becquerel – Biographical"). Using this new knowledge, Marie and Pierre Curie experimented with radioactivity and discovered two new radioactive elements, polonium and radium ("Marie Curie."). In the early 1900's Ernest Rutherford revolutionized atomic theory by proving the existence of a positively charged nucleus and in 1905, Einstein's theory of relativity signaled the beginning of the Atomic Age ("Albert Einstein," "The Gold Foil Experiment."). Several years later, in 1939, Otto Hahn and Fritz Strassman discovered the concept of nuclear fission, leading to Enrico Fermi's experiments with nuclear chain reactions.

In 1942, Fermi successfully created a nuclear chain reaction under the Stagg Field at the University of Chicago, and shortly thereafter, the Manhattan Project was created with the mission of building the world's first atomic bomb ("Enrico Fermi - Biographical"). Robert Oppenheimer, Fermi, and several others were sent to remote location in New Mexico to build 'the gadget.' Within a short period of time, the top-secret work at Los Alamos led to the development of a device ready to be tested. On July 16, 1945, Robert Oppenheimer and his team of scientists detonated the first atomic bomb, changing the course of the war and of history ("The Manhattan Project.").

2. NUCLEAR POWER TODAY

While nuclear material is most commonly associated with nuclear weapons, there are several other important uses. Nuclear materials can be used to generate power through contained nuclear fission reactions. The heat produced by such reactions is used to convert water into steam, which then powers generators that convert the mechanical energy into electricity ("Nuclear Power Plants."). In spite of extreme precaution in the building and operation of these plants, they can still be very dangerous. Following the incidents at the Chernobyl and Fukushima nuclear power plants, both domestic and international agencies have implemented new safety measures designed to prevent those kind of accidents from happening in the future. The International Atomic Energy Agency also works to ensure that all facilities containing significant quantities of nuclear material are following international regulations ("Atoms for Peace.").

X-ray machines, CAT scans, and many cancer treatments use radioactive materials. Medical radiation is a significant source of man-made radiation which has led to an increase in the average radiation dose a person can receive in their lifetime (Szaflarski). Even so, the use of nuclear material in medicine has led to vast improvements in diagnostic practices and treatment methods for cancer and other such diseases.

3. NUCLEAR FORENSICS

Following the terrorist attacks of September 11, it is clear that a nuclear attack is a very real and serious possibility. Accompanying an increase in nuclear safeguards and surveillance, a new branch of forensic science has been initiated to focus on the prevention of nuclear terrorism.

Nuclear Forensics is a growing field that is concerned with all stages of the process of creating and detonating a nuclear weapon. The main goal is to prevent nuclear attack by locating and securing nuclear material before it can be used in an aggressive manner. This stage of the process is mostly paperwork; laws, regulations, treaties, and declarations made by individual countries or by the UN Security Council. There is some preliminary leg work done in the form of field testing detection equipment and tracking down orphan materials, however none of these have yielded any spectacular or useful results.

In the event of a nuclear attack, the fist step is to analyze the post detonation debris to aid in the identification of the responsible party. This aspect of the nuclear forensics process, while reactionary, is more scientific. A rock sample taken from the detonation site can be dissolved into liquid form and analyzed to determine its chemical composition. The chemical analysis of spent nuclear material can provide valuable information if properly processed and analyzed.

In order to accurately evaluate the results, scientists require information on the natural occurring elements in the detonation zone. From this information, scientists can determine what percentage of the element originated the bomb itself rather than the environment.

4. DATA: SOIL CONCENTRATIONS

The following data set (Tables 1 – 3) contains element concentrations from sixty-nine different cities including the US capitals, the twenty most populous cities in the US, Baltimore and Washington D.C. Cities with no data available are not listed. Information has been collected from the U.S Geological Survey using an interactive map. Links to the specific data locations are listed at the end of this paper.

1. Data from National Geochemical Survey

City	Uranium	Silicon	Iron	Thorium	Strontium	Barium
Albuquerque, NM	<100 ppm	N/A	2.55%	11 ppm	232 ppm	662 ppm
Annapolis, MD	<100 ppm	N/A	5.57%	8 ppm	55 ppm	156 ppm
Atlanta, GA	<100 ppm	N/A	0.49%	33 ppm	72 ppm	605 ppm
Augusta, ME	<100 ppm	31.50%	2.93%	13 ppm	117 ppm	416 ppm
Baton Rouge, MD	<100 ppm	N/A	1.59%	9 ppm	91 ppm	472 ppm
Bismarck, ND	<100 ppm	N/A	2.55%	14 ppm	78 ppm	565 ppm
Boise, ID	<100 ppm	N/A	1.70%	19 ppm	390 ppm	1030 ppm
Carson City, NV	<100 ppm	N/A	0.76%	<6 ppm	397 ppm	1240 ppm
Charleston, WV	<100 ppm	N/A	2.61%	14 ppm	76 ppm	521 ppm
Cheyenne, WY	<100 ppm	N/A	2.57%	14 ppm	164 ppm	710 ppm
Chicago, IL	<100 ppm	N/A	2.47%	6 ppm	140 ppm	550 ppm
Columbus, OH	<100 ppm	N/A	2.72%	11 ppm	97 ppm	519 ppm
Concord, NH	<100 ppm	33.88%	1.61%	26 ppm	168 ppm	342 ppm
Dallas, TX	<100 ppm	N/A	0.96%	10 ppm	27 ppm	112 ppm
Des Moines, IA	<100 ppm	N/A	2.00%	10 ppm	163 ppm	584 ppm
Detroit, MI	<100 ppm	N/A	1.86%	<6 ppm	201 ppm	376 ppm
Dover, DE	<100 ppm	N/A	2.24%	11 ppm	78 ppm	494 ppm
El Paso, TX	<100 ppm	N/A	2.90%	8 ppm	430 ppm	860 ppm
Fort Worth, TX	<100 ppm	N/A	2.67%	10 ppm	241 ppm	207 ppm
Frankfort, KY	<100 ppm	N/A	4.24%	9 ppm	134 ppm	317 ppm
Hartford, CT	<100 ppm	32.97%	2.71%	15 ppm	110 ppm	272 ppm
Houston, TX	<100 ppm	N/A	0.48%	<6 ppm	10 ppm	195 ppm
Indianapolis, IN	<100 ppm	N/A	1.88%	<6 ppm	201 ppm	251 ppm
Jackson, MS	<100 ppm	78.20%	2.60%	12 ppm	73 ppm	536 ppm
Jacksonville, FL	<100 ppm	92%	0.39%	8 ppm	30 ppm	99 ppm
Jefferson City, MO	<100 ppm	N/A	1.96%	10 ppm	73 ppm	635 ppm
Juneau, AK	<100 ppm	N/A	5.46%	14 ppm	170 ppm	2370 ppm
Lincoln, NE	<100 ppm	N/A	2.32%	10 ppm	149 ppm	786 ppm
Little Rock, AR	<100 ppm	N/A	2.58%	12 ppm	58 ppm	304 ppm
Los Angeles, CA	<100 ppm	N/A	3.50%	15 ppm	499 ppm	888 ppm
Montpelier, VT	<100 ppm	28.21%	5.71%	10 ppm	97 ppm	117 ppm
Nashville, TN	<100 ppm	N/A	3.99%	12 ppm	187 ppm	424 ppm
Oklahoma City, OK	<100 ppm	N/A	1.60%	8 ppm	68 ppm	769 ppm
Phoenix, AZ	<100 ppm	N/A	4.17%	12 ppm	336 ppm	610 ppm
Pierre, SD	<100 ppm	N/A	2.03%	8 ppm	151 ppm	780 ppm
Raleigh, NC	<100 ppm	N/A	3.10%	14 ppm	193 ppm	644 ppm
Richmond, VA	<100 ppm	N/A	2.96%	13 ppm	27 ppm	232 ppm
Sacramento, CA	<100 ppm	N/A	2.77%	6 ppm	214 ppm	553 ppm
Salem, OR	<100 ppm	N/A	7.68%	12 ppm	133 ppm	585 ppm
Salt Lake City, UT	<100 ppm	N/A	1.92%	11 ppm	99 ppm	366 ppm
San Antonio, TX	<100 ppm	N/A	2.15%	<6 ppm	192 ppm	190 ppm
San Jose, CA	<100 ppm	N/A	3.51%	9 ppm	1443 ppm	585 ppm
Santa Fe, NM	<100 ppm	N/A	5.83%	20 ppm	198 ppm	782 ppm
Springfield, IL	<100 ppm	N/A	2.57%	12 ppm	107 ppm	641 ppm
Tallahassee, FL	<100 ppm	N/A	1.14%	10 ppm	98 ppm	230 ppm

Topeka, KS	<100 ppm	N/A	2.20%	9 ppm	112 ppm	483 ppm

2. Data from National Uranium Resource Evaluation Program

City	Uranium	Iron	Thorium	Strontium	Barium
Albany, NY	0.5 ppm	2.73%	5 ppm	N/A	212 ppm
Annapolis, MD	12.1 ppm	5.00%	58 ppm	N/A	N/A
Atlanta, GA	7.5 ppm	3.28%	24 ppm	N/A	128 ppm
Augusta, ME	2.3 ppm	2.64%	6 ppm	102 ppm	348 ppm
Austin, TX	2.5 ppm	1.88%	10 ppm	145 ppm	291 ppm
Boise, ID	3.3 ppm	2.29%	12 ppm	350 ppm	808 ppm
Carson City, NV	1.9 ppm	2.30%	6 ppm	60 ppm	382 ppm
Cheyenne, WY	3 ppm	1.93%	8 ppm	172 ppm	607 ppm
Columbia, SC	25.1 ppm	2.71%	120 ppm	<50 ppm	N/A
Concord, NH	4.6 ppm	2.71%	23 ppm	53 ppm	123 ppm
Dallas, TX	1.7 ppm	1.35%	<2 ppm	731 ppm	177 ppm
Denver, CO	5 ppm	8.10%	18.8 ppm	670 ppm	677 ppm
Dover, DE	8.1 ppm	9.57%	35 ppm	N/A	N/A
Fort Worth, TX	1.5 ppm	1.51%	6 ppm	400 ppm	143 ppm
Harrisburg, PA	0.3 ppm	2.92%	8 ppm	N/A	227 ppm
Hartford, CT	9.9 ppm	7.03%	32 ppm	N/A	N/A
Helena, MT	3.1 ppm	1.33%	10.6 ppm	<321 ppm	705 ppm
Juneau, AK	1.35 ppm	8.98%	<1.9 ppm	<411 ppm	<207 ppm
Lincoln, NE	3 ppm	2.39%	8 ppm	178 ppm	827 ppm
Little Rock, AR	2.2 ppm	3.15%	10 ppm	N/A	55.3%
Montgomery, AL	55.3 ppm	4.14%	357 ppm	N/A	N/A
Montpelier, VT	2 ppm	<0.93%	5 ppm	N/A	N/A
Oklahoma City, OK	1.84%	0.72%	6 ppm	79 ppm	1613 ppm
Phoenix, AZ	2.5 ppm	4.62%	17 ppm	N/A	N/A
Providence, RI	2.8 ppm	1.57%	5 ppm	N/A	N/A
Raleigh, NC	13.9 ppm	2.11%	2 ppm	N/A	32 ppm
Richmond, VA	8.7 ppm	4.49%	27 ppm	N/A	N/A
Sacramento, CA	2.8 ppm	3.46%	4 ppm	196 ppm	511 ppm
Salt Lake City, UT	4.2 ppm	2.53%	11 ppm	153 ppm	964 ppm
San Antonio, TX	2.03 ppm	N/A	<400 ppm	N/A	100 ppm
Santa Fe, NM	4.77 ppm	4.52%	17.5 ppm	<252 ppm	468 ppm
Trenton, NJ	0.8 ppm	3.90%	25 ppm	N/A	107 m

Data from Rock Analysis

City	U	Si	SiO2	CaO	K2O	Na2O	Al2O3	Fe	Th	Sr	Ba
Albuquerque, NM	N0 ppm	G10 %	50.90 %	9.20 %	0.42 %	2.39 %	16 %	7 %	N0 ppm	700 ppm	150 ppm
Atlanta, GA	0.19 ppm	27 %	58.30 %	0.06 %	L0.02 %	L0.15 %	0.91 %	5.49 %	0.5 ppm	L15 ppm	L90 ppm
Augusta, ME	N0 ppm	N/A	55.80 %	5.80 %	1.50 %	0.20 %	16 %	N/A	N0 ppm	500 ppm	150 ppm
Austin, TX	N/A	N/A	N/A	0.44 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Baltimore, MA	L0.4ppm	N/A	47.90 %	10.80 %	0.38 %	2.56 %	15.40 %	8.86 %	L0.2 ppm	89 ppm	36 ppm
Boise, ID	N/A	N/A	72.10 %	2.34 %	2.78 %	4.03 %	15.20 %	N/A	N/A	570 ppm	1390 ppm
Carson City, NV	4.25 ppm	N/A	N/A	N/A	N/A	N/A	N/A	0.80 %	12.5 ppm	L100 ppm	644 ppm
Charleston, WV	L220 ppm	28 %	56.40 %	0.45 %	0.16 %	L0.15 %	27.50 %	0.64 %	L46 ppm	350 ppm	90 ppm
Charlotte, NC	N/A	N/A	53 %	9.90 %	0.50 %	2.50 %	17.10 %	N/A	N/A	N/A	N/A
Cheyenne, WY	7.31 ppm	N/A	73.70 %	0.83 %	5.74 %	1.67 %	11.70 %	N/A	30 ppm	0.01 %	N/A
Columbia, SC	N0 ppm	N/A	72.30 %	1.30 %	0.35 %	5.50 %	11.50 %	N/A	N0 ppm	70 ppm	150 ppm
Columbus, OH	N0 ppm	N/A	N/A	N/A	N/A	N/A	N/A	1.50 %	N0 ppm	500 ppm	100 ppm
Concord, NH	L0.8 ppm	N/A	69.30 %	3.70 %	1.50 %	4 %	16.90 %	2.00 %	6 ppm	N/A	264 ppm
El Paso, TX	N0 ppm	G10 %	62.50 %	3.60 %	2.40 %	5.60 %	18.30 %	3 %	N0 ppm	1500 ppm	1500 ppm
Frankfort, KY	L215 ppm	0.59 %	0.80 %	54.40 %	0.11 %	0.10 %	0.16 %	0.27 %	L21.5 ppm	G464 ppm	130 ppm
Harrisburg, PA	L0.6 ppm	N/A	52.10 %	12.10 %	0.42 %	1.84 %	14.70 %	7.03 %	1.5 ppm	199 ppm	122 ppm
Hartford, CT	L220 ppm	G34 %	N/A	N/A	N/A	N/A	N/A	6.20 %	L46 ppm	23 ppm	180 ppm
Honolulu, HI	N/A	N/A	45 %	2.23 %	L0.002%	0.09 %	2.41%	N/A	N/A	N/A	N/A
Jefferson City, MO	N0 ppm	G10 %	41 %	0.20 %	1.30 %	0.08 %	33 %	0.50 %	N0 ppm	150 ppm	30 ppm

Juneau, AK	0.33 ppm	N/A	50.20 %	7.91 %	0.44 %	4.10 %	14 %	7.01 %	0.74 ppm	250 ppm	90 ppm
Little Rock, AR	N0 ppm	G10 %	N/A	N/A	N/A	N/A	N/A	5.00 %	N0 ppm	100 ppm	300 ppm
Los Angeles, CA	0.73 ppm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.5 ppm	N/A	N/A
Montpelier, VT	L400 ppm	N/A	42.70 %	0.03 %	L0.02 %	L0.15 %	1.11 %	5.60 %	L20 ppm	L8 ppm	L4 ppm
Nashville, TN	L100 ppm	N/A	N/A	N/A	N/A	N/A	N/A	5.90 %	L5 ppm	47 ppm	160 ppm
New York, NY	L215 ppm	24.30 %	52.40 %	10.70 %	0.64 %	2 %	15 %	10.20 %	L21.5 ppm	237 ppm	215 ppm
Oklahoma City, OK	1.15 ppm	N/A	N/A	N/A	N/A	N/A	N/A	3.50 %	4.64 %	44 ppm	66 ppm
Phoenix, AZ	2.02 ppm	N/A	N/A	7.89 %	1.93 %	3.59 %	14.70 %	6.51 %	6.18 %	1000 ppm	1700 ppm
Pierre, SD	N0 ppm	N/A	N/A	N/A	N/A	N/A	N/A	5.00 %	N0 ppm	70 ppm	500 ppm
Providence, RI	0.27 ppm	N/A	47.20 %	12.50 %	0.74 %	1.42 %	16.40 %	8.23 %	0.94 ppm	286 ppm	167 ppm
Raleigh, NC	0.33 ppm	N/A	47.70 %	10 %	0.34 %	2.40 %	16.40 %	9.48 %	0.74 ppm	360 ppm	71 ppm
Richmond, VA	L215 ppm	32.80 %	73.20 %	1.20 %	4.90 %	3.40 %	14.60 %	0.79 %	L21.5 ppm	173 ppm	537 ppm
Salem, OR	N/A	G10 %	54.80 %	6.90 %	0.82 %	3.50 %	17.90 %	7.00 %	N0 ppm	200 ppm	300 ppm
Salt Lake City, UT	N0 ppm	N/A	N/A	N/A	N/A	N/A	N/A	0.15 %	N0 ppm	200 ppm	50 ppm
San Francisco, CA	N0 ppm	G10 %	71.60 %	1.50 %	2.30 %	3 %	13.90 %	2 %	N0 ppm	200 ppm	500 ppm
Santa Fe, NM	17.2 ppm	N/A	49.90 %	10.10 %	0.58 %	2.40 %	13.30 %	0.90 %	43.2 ppm	L110 ppm	102 ppm
Seattle, WA	N/A	N/A	59.30 %	5.70 %	1.01 %	4.81 %	17.90 %	N/A	N/A	N/A	N/A
Springfield, IL	L100 ppm	N/A	N/A	N/A	N/A	N/A	N/A	3.70 %	9 ppm	120 ppm	270 ppm
Topeka, KS	N0 ppm	1.50 %	N/A	N/A	N/A	N/A	N/A	1.00 %	N0 ppm	700 ppm	30 ppm
Trenton, NJ	0.82 ppm	N/A	N/A	N/A	N/A	N/A	N/A	9.02 %	3.6 ppm	257 ppm	235 ppm
Washington D.C.	N0 ppm	G10 %	55.10 %	0.08 %	0.11 %	0.08 %	4.20 %	7 %	N0 ppm	30 ppm	3000 ppm

5. DATA FROM BUILDING MATERIALS

The following data set (Table 4) lists activity concentrations for Uranium, Thorium, Potassium, and Radium in various building materials. This data is important for analyzing element concentrations of post-detonation debris from an urban area. Using this information, scientists can determine the amount of these elements in a sample that came from the existing building materials.

4. Activity Concentrations in Building Materials

Building Material	232 Th Bq/kg	226Ra Bq/kg	40K Bq/kg	238U Bq/kg
Aerated clay	20	30	570	N/A
Aerated concrete w/shale	30	25	1180	N/A
Aerated schist	50	60	860	N/A
Brick	46.88	21.7	406.6	73
Brick w/fly ash	105	135	140	N/A
Cement	55.2	25.8	299.8	98
Concrete w/coal fly ash	50	10	450	N/A
Concrete w/ copper slag	65	35	970	N/A
Copper slag	230	40	730	N/A
Dholpur stone	33	N/A	1425	49
Foundry slag	75	60	120	N/A
Granite	98.8	49.4	1456.1	82
Hematite aggregate	26	N/A	288	68
Lignite fly ash	55	25	310	N/A
Marble	BDL	N/A	230	29
Mosaic tile	76	N/A	353	85
Ordinary aggregate	67	N/A	1009	60
Radiation shielding bricks	109	N/A	1030	89
Rocks	11.7	6.6	217.6	N/A

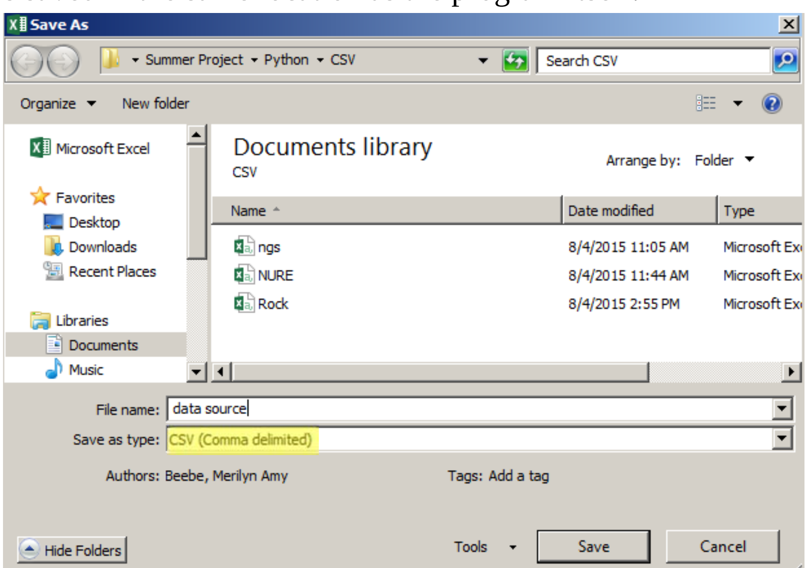
Sand	38.8	11.4	743.3	40
Sedam cement	29.4	25.8	259.6	N/A
Slag stone	45	60	90	N/A
Soil	20	N/A	200	30
Stone w/ coal fly ash	85	65	910	N/A

BDL = below detectible level

6. USING PYTHON

The data has been formatted so that it can be accessed through a python program. Python is the program of choice as it is simple and has wide uses. A brief description of the program and its interface follows.

This program made use of the CSV module in Python. This module allows programmers to access data stored in CSV files and run that data through a program. The first step in writing this program is to convert the desired data source into a CSV file. It is also important to ensure that the data file is saved in the same location as the program itself.

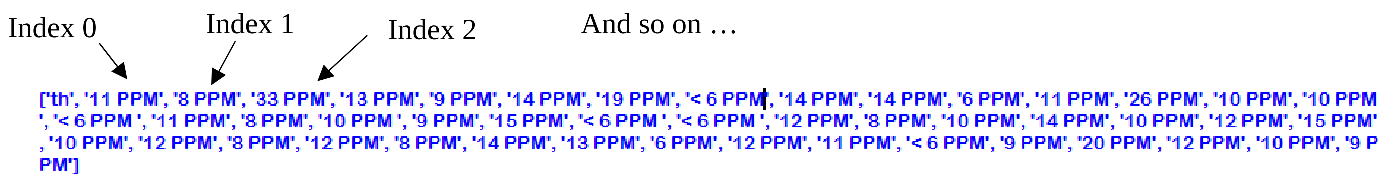


After setting up the CSV module in the program, the data is assigned to lists. The first column of the excel file lists the cities where data was found. The program stores each of these cities into a list. The same is done for the columns containing the data. Each city is assigned an index within the city list.

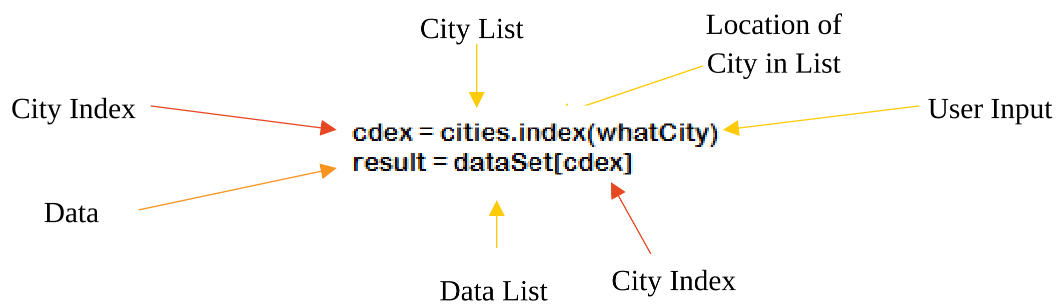
Index 0 Index 1 Index 2 And so on …

['', 'ALBUQUERQUE', 'ANNAPOLIS', 'ATLANTA', 'AUGUSTA', 'BATON ROUGE', 'BISMARCK', 'BOISE', 'CARSON CITY', 'CHARLESTON', 'CHEYENNE', 'CHICAGO', 'COLUMBUS', 'CONCORD', 'DALLAS', 'DES MOINES', 'DETROIT', 'DOVER', 'EL PASO', 'FORT WORTH', 'FRANKFORT', 'HARTFORD', 'HOUSTON', 'INDIANAPOLIS', 'JACKSON', 'JACKSONVILLE', 'JEFFERSON CITY', 'JUNEAU', 'LINCOLN', 'LITTLE ROCK', 'LOS ANGELES', 'MONTPELIER', 'NASHVILLE', 'OKLAHOMA CITY', 'PHOENIX', 'PIERRE', 'RALEIGH', 'RICHMOND', 'SACRAMENTO', 'SALEM', 'SALT LAKE CITY', 'SAN ANTONIO', 'SAN JOSE', 'SANTA FE', 'SPRINGFIELD', 'TALLAHASSEE', 'TOPEKA']

This index corresponds to the location data from that city in the data list.



indexes and produces the data.



The result, depending on the user inputs, looks something like this:

The element concentration of THORIUM in TOPEKA is 9 PPM

Finally, the program contains a repeat sequence that allows the user to conduct multiple searches before exiting the program.

```
again= True
while again:
  choice = raw_input('Do you want to make another search (yes/no)?')
  if choice == 'no':
    print
    print('Hit enter to exit')
    print
    again = False
  elif choice == 'yes':
    print
    print(data())
    print
  else:
    print
    print('You did not enter a valid choice.')
    print
```

The whole program consists of approximately 100 lines of code. This program, not including the code written in the CSV module, is very short, and this method for storing and accessing the data was the simplest and easiest to modify. Wherever possible, variables are used so that any updates made effect the entire program. In addition, the lines of code that read ‘print,’ do not have a real purpose in the program other than to make the output easy to read. The use of the CSV made it possible to catalog and access the data using Excel rather than logging all of the data in the program itself.

SOURCES

"Albert Einstein." *Bio*. A&E Television Networks, 2015. Web. 21 July 2015. http://www.biography.com/people/albert-einstein-9285408#final-years

"Atoms for Peace." *Atoms for Peace*. IAEA, n.d. Web. 20 July 2015. https://www.iaea.org/about

"Enrico Fermi - Biographical". *Nobelprize.org*. Nobel Media AB 2014. Web. 14 Jul 2015. http://www.nobelprize.org/nobel_prizes/physics/laureates/1938/fermi-bio.html

"Henri Becquerel - Biographical". *Nobelprize.org*. Nobel Media AB 2014. Web. 14 Jul 2015. http://www.nobelprize.org/nobel_prizes/physics/laureates/1903/becquerel-bio.html

"Marie Curie." *Bio*. A&E Television Networks, 2015. Web. 14 July 2015. http://www.biography.com/people/marie-curie-9263538#video-gallery

"Nuclear Power Plants." *Nuclear Power Plants*. Ready, 02 Nov. 2013. Web. 20 July 2015. http://www.ready.gov/nuclear-power-plants

Szaflarski, Diane, Robert Dean, and Melaine Dean. "Nuclear Chemistry." *Nuclear Chemistry*. DOE, n.d. Web. 20 July 2015. http://people.chem.duke.edu/~jds/cruise_chem/nuclear/exposure.html

"The Advancement of Nuclear Chemistry." *Timetoast*. N.p., n.d. Web. 14 July 2015. http://www.timetoast.com/timelines/the-advancement-of-nuclear-chemistry

"The Gold Foil Experiment." *The Gold Foil Experiment*. N.p., n.d. Web. 14 July 2015. http://myweb.usf.edu/~mhight/goldfoil.html

"The Manhattan Project." *Ushistory.org*. Independence Hall Association, n.d. Web. 14 July 2015. http://www.ushistory.org/us/51f.asp

"Wilhelm Conrad Röntgen - Biographical". *Nobelprize.org*. Nobel Media AB 2014. Web. 14 Jul 2015. http://www.nobelprize.org/nobel_prizes/physics/laureates/1901/rontgen-bio.html

"Your Geography Selections." *American FactFinder*. U.S Census Bureau, Population Division, May 2015. Web. 18 June 2015. http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk

National Geochemical Survey Data

"National Geochemical Survey Database." *National Geochemical Survey Database*. USGS, 03 Sept. 2014. Web. 20 July 2015. http://mrdata.usgs.gov/geochemistry/ngs.html

Los Angeles: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-195964

Chicago: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=D-305577

Houston: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-155090

Phoenix: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-180488

San Antonio: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-149739

Dallas: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-155171

San Jose: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-196079

Jacksonville: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-112206

Indianapolis: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-261788

Columbus: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-258007

Fort Worth: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-161767

Detroit: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-194538

El Paso: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=D-558899

Albuquerque: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-159015

Santa Fe: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-165150

Juneau: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-178683

Little Rock: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-127241

Sacramento: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-165147

Hartford: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-145708

Dover: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-211251

Tallahassee: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-123498

Atlanta: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-211738

Boise: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-168047

Springfield: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-224605

Des Moines: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-236357

Topeka: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-279425

Frankfort: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-256099

Baton Rouge: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-183789

Augusta: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-148047

Annapolis: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-117040

Jackson: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-102902

Jefferson City: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-262073

Lincoln: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-150069

Carson City: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-164137

Concord: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-145806

Raleigh: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-210806

Bismarck: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-255370

Oklahoma City: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-152447

Salem: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-262410

Pierre: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-297871

Nashville: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-279056

Salt Lake City: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-144767

Montpelier: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-148423

Richmond: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-211701

Charleston: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-143526

Cheyenne: http://mrdata.usgs.gov/ngs/show-ngs.php?labno=C-152103

National Uranium Resource Evaluation Data

"Geochemistry of Stream Sediments from NURE-HSSR." *Geochemistry of Stream Sediments from NURE-HSSR*. USGS, 03 Sept. 2014. Web. 20 July 2015. http://mrdata.usgs.gov/geochemistry/nuresed.html

Phoenix: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5206016

San Antonio: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5237110

Dallas: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5242174

Austin: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5247929

Fort Worth: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5242127

Montgomery: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5268422

Juneau: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=7020084

Little Rock: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5252112

Sacramento: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5190291

Denver: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5078759

Hartford: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5329804

Dover: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5313307

Atlanta: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5276853

Boise: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5180136

Augusta: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5275377

Annapolis: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5311258

Helena: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5023390

Lincoln: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5214684

Carson City: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5154056

Concord: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5326626

Trenton: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5315016

Santa Fe: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5107835

Albany: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5317008

Raleigh: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5287290

Oklahoma City: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5242991

Harrisburg: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5314096

Providence: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5327748

Columbia; http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5294723

Salt Lake City: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5106472

Montpelier: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5322754

Richmond; http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5304343

Cheyenne: http://mrdata.usgs.gov/nuresed/show-nuresed.php?rec_no=5050659

Rock Data

"National Geochemical Database: Rock." *National Geochemical Database: Rock*. USGS, 03 Sept. 2014. Web. 20 July 2015. http://mrdata.usgs.gov/geochemistry/ngdbrock.html

New York: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W177284

Los Angeles: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D219632

El Paso: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D154981

Albuquerque: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D178443 http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D163055

Phoenix: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=M201019

Seattle: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D563851

Charlotte: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W207654

Washington D.C.: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W170069

Baltimore: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D539118

Austin: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D183421

San Francisco: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=M120466

Columbus: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D124008

Juneau: http://mrdata.usgs.gov/ngdbrock/show-ngdbrock.php?lab_id=M174567

Little Rock: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D116559

Hartford: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W237385

Atlanta: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W215182

Boise: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D345878

Honolulu: http://mrdata.usgs.gov/ngdbrock/show-ngdbrock.php?lab_id=M126256

Springfield: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D517473

Topeka: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D148145

Frankfort: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W182677

Augusta: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W172068

Jefferson City: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D150445

Carson City: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D236160

Concord: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W196609

Trenton: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W243095

Santa Fe: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W193230

http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D191472

Raleigh: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W231948

Oklahoma City: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D290526

Salem: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id= D290526

Harrisburg: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W243867

Providence: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W251884

Columbia: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W179520

Pierre: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D155231

Nashville: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D236689

Salt Lake City: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D163680

Montpelier: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D577702

Richmond: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W182140

Charleston: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=W220493

Cheyenne: http://mrdata.usgs.gov/ngdb/rock/show-ngdbrock.php?lab_id=D122240

Building Materials

Keller, G., B. Hoffmann, and T. Feigenspan. "Radon Permeability and Radon Exhalation of Building Materials." *Science Direct*. Elsevier, 14 May 2001. Web. 20 July 2015.

Kerur, Basavaraj R., Tanakanti Rajeshwari, Rajesh Siddanna, and Anil S. Kumar. "2013 Acta Geophysica Full." *ResearchGate*. Versits, n.d. Web. 20 July 2015.

Sonkawade, R. G., K. Kant, S. Muralithar, R. C. Ramola, and R. Kumar. "Natural Radioactivity in Common Building Construction and Radiation Shielding Materials." *Science Direct*. Elsevier, Mar. 2008. Web. 20 July 2015.