

Limitations of Cancer Ecologic Studies of Populations near U.S. Nuclear Plant Sites

by

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Abstract

This paper examines whether cancer mortality resulting from routine radioactive emissions from U.S. nuclear power plants can be statistically deduced from county-wide cancer mortality data. We conclude that ecologic epidemiological studies using county-wide cancer mortality data will shed no light on the question of the excess cancer mortality to the exposed population that may be attributable to radioactive releases from nuclear power plants. While our analysis is limited to county-wide mortality related to all cancer sites, for all races, both sexes and all ages, the technique we have used could be applied to specific cancer types and smaller cohorts. However, we doubt that this would lead to a different conclusion.

U.S. Nuclear Plant Site Data

There are 104 U.S. operational nuclear power plants at 65 generating stations at 64 sites in 63 counties (Table 1). Salem and Hope Creek Generating Stations are treated as a single site. Since the Nine Mile Point and James A. FitzPatrick Nuclear Stations are in close proximity within the same county, for our analysis they are also treated as a single site. Therefore, in this report we will be referring to 63 instead of 64 sites in separate counties. We have not examined reactor sites where there are no longer any operational reactors.

There are approximately 857,000 people in 131 counties within 5 miles of the 63 sites, and 3,895,000 in 184 counties within 10 miles of the sites.¹ There are 19 sites where the 5 mi-area is entirely within a single county, 26 sites where the 5 mi-area overlaps two counties, 12 where it overlaps 3 counties and 6 where it overlaps 4 counties. In the 63 counties where operational plants are located, the average county-wide population for the period 2003-2007 ranged from a low of 6,949 (Surry Nuclear Power Station, Surry Co., VA) to a high of 3,638,047 (Palo Verde Nuclear Power Station, Maricopa Co., AZ).² In the later case, while the population density near the reactor is low, the county includes the city of Phoenix some 40 miles distant. Two other sites are within counties that have more than 1,000,000 people—San Onofre Nuclear Generating Station in San Diego Co., CA with an average population of 2,945,427, and Turkey Point Power Station in Miami-Dade Co., FL with an average population of 2,407,945.

Of the 63 sites, there are only 17 sites where the county boundary is greater than two miles from the site, and only seven sites where the county boundary is greater than five miles from the site. This places a large constraint on using county-wide cancer statistics to assess cancer mortality due to emissions from the nuclear plants. More than twenty sites are located at or near large bodies of water—Atlantic Ocean (3), Pacific Oceans (2), Gulf of New Mexico (2), Great Lakes (7), Hudson River (1), Chesapeake Bay (1), Delaware Bay (1) and other bays and sounds (4). In these cases a large fraction of the released radioactive materials would pass over water rather than over populated areas.

¹ This is less than the population summed in Table 1. Nine Mile Point and James A. FitzPatrick Nuclear Stations, treated separately in Table 1, are in close proximity. Thus, Table 1 double counts much of the population around these two stations.

² U.S. Census data can be found at <http://www.census.gov/popest/counties/CO-EST2009-01.html>

Within the 5 mi-area within the 63 counties where plant sites are located, the off-site population ranges from essentially zero (Columbia Generation Station on the Hanford Reservation, Benton Co., WA) to a high of 68,170 (Limerick Generating Station, Montgomery Co., PA).

Several sites are at or near other sites where nuclear activities have released significant amounts of radioactive material—Columbia Generation Station is on the Hanford Reservation and Alvin W. Vogtle Nuclear Power Station is near the Savannah River Site. Three Mile Island Generating Station is the location of TMI-1, which incurred a partial core meltdown and was shut down; and the Enrico Fermi Atomic Power Plant is the location of Fermi-1, which also incurred a partial core meltdown and was shut down.

Analysis of County-wide Cancer Data

In our analysis we have used age adjusted county-wide cancer mortality data averaged over the period 2003-2007, reported by the National Cancer Institute (NCI).³ Federal data systems in the United States have cancer mortality data only at the county, state and national levels. We have not explored data that may be available from systems at the state or county level. As seen from Figures 1 through 5, there is a wide range in the age adjusted cancer mortality rate among counties throughout the United States, irrespective of the location of nuclear plants. For the period 2003-2007, the age adjusted annual rate of cancer mortality in the 63 counties where nuclear plants are located ranged from a low of 153.1 cancers deaths per year per 100,000 persons to a high of 247.4 cancers deaths per year per 100,000 persons (Table 2). The average for the United States is 183.8 cancers deaths per year per 100,000 persons for the same 2003-2007 period. In other words, in the 63 counties of where nuclear plants are located the cancer mortality rate varied from 16.7 percent below the national average to 34.6 percent higher than the national average. In the 63 counties where nuclear plants are located the weighted average cancer death rate is 174.7, which is below the national average. The estimated total 2010 population of all 63 counties is 19,638,000. Thus, one would expect about 34,000 cancer deaths per year in these counties. Approximately 1,625 cancer deaths per year occur among the 857,000 peoples living within 5 miles of U.S. nuclear plants, and about 7,400 cancer deaths per year within 10 miles of the plants.

Together with the annual cancer mortality risk estimates by county, the NCI also reports the 95% confidence limits on these risk estimates. These 95% confidence limits average (-7.35%, +8.05%) and range from a low of 1.3% (San Onofre Nuclear Generating Station, San Diego Co., CA) to a high of 26.4% (Comanche Peak Steam Electric Station, Somervell Co., TX). The uncertainty in the county-wide cancer deaths per year during 2003-2007 ranged from a low of 3.98 cancer deaths (Surry Nuclear Power Station, Surry Co., VA) and 4.04 cancer deaths/year (Cooper Nuclear Station, Nemaha Co., NE) to a high of 55.5 cancer deaths/year (Turkey Point Power Station, Miami-Dade Co., FL).

For the period 2003-2007, in the 63 counties where nuclear plants are located the number of county-wide cancer deaths per year ranged from a low of 14 cancer death/year (Comanche Peak

³ National Cancer Institute, "State Cancer Profiles":
<http://statecancerprofiles.cancer.gov/cgi-bin/deathrates/deathrates.pl?05&001&00&0&001&1&1&1>

Steam Electric Station, Somervell Co., TX) to a high of 5,272 cancer death/year (Palo Verde Nuclear Power Station, Maricopa Co. AZ).

We want to compare the age adjusted cancer death rates in the 63 counties where nuclear plants are located with the cancer death rates of 63 “control” counties. To select the controls, for each of the 63 counties where nuclear plants are located we selected the county in the same state that had a population closest to that of the county containing the nuclear plant, but exclusive of counties within 5 miles of the plant. We then rank ordered the two sets of counties according to their cancer death rates. In Figure 6, the lines are the rank ordering of the mean cancer death rates, together with the upper and lower 95% confidence limits, for the 63 counties containing nuclear plants. These lines are superimposed upon the 95% confidence limits of the control counties. From this figure we conclude that the age adjusted cancer deaths rates in the two sets of counties are statistically indistinguishable. Thus, cancer mortality due to routine radioactive releases from U.S. nuclear power plants cannot be statistically deduced from county-wide cancer mortality data.

In Figure 7 we have done a similar analysis for a subset of 51 counties with nuclear plants and their 51 control counties. In this case we have removed from the full list of 63 counties those counties where: a) the plant is at or near another large radioactive releases source (Hanford and Savannah River Site), b) the population difference between the county with the nuclear plant and that of the control county was greater than 30 percent, and c) a reactor at the site had a partial core meltdown. The counties removed contained the following nuclear stations:

category a): Columbia and Alvin W. Vogtle

category b): Palo Verde W.B. McGuire; Monticello; Millstone; Salem and Hope Creek; Shearon Harris; Turkey Point; and Seabrook

category c) Three Mile Island and Enrico Fermi.

We draw the same conclusion from Figure 7, namely, potential cancer mortality due to routine radioactive emissions from U.S. nuclear power plants cannot be statistically deduced from county-wide cancer mortality data.

We have also examined this issue taking a different approach. Here we assume radiation exposures to the public from routine releases are dominated by exposures within 5 miles of the reactor site. Using BEIR VII best estimate cancer risks⁴—57 cancer deaths per 100,000 person-rem—we have estimated the collective dose, to this population that would be required to produce cancer deaths (over their lifetimes) comparable to the uncertainty in the annual county-wide cancer death rate statistics. The best estimate of the collective dose required to produce 3.98 cancer deaths (the lowest annual 95% confidence interval in the annual number of cancer

⁴ National Research Council, *Health Risks from Exposure to Low Levels of Ionizing Radiation, BEIR VII Phase 2*, The National Academies Press, Washington, D.C., 2006, Table ES-1, p. 15 and Table 12-13, p. 291. We have averaged the BEIR VII risk estimates for male and female after totaling the risks for solid tumors and leukemia. According to the BEIR Committee, “At doses less than 40 times the average yearly background exposure (100 mSv) [less than 10 rem], statistical limitations make it difficult to evaluate human cancer risk in humans. A comprehensive review of the biological data led the committee to conclude that the risk would continue in a linear fashion at lower doses without a threshold and that the smallest dose has the potential to cause a small increase in risks to humans.” BIER VII, Phase 2, p. 7.

deaths) is 6,949 person-rem (Surry Nuclear Power Station, Surry Co., VA). But if this collective dose were the result of radioactive releases from the Surry Nuclear Power Station, any resulting cancers would occur not in a single year, but over the lifetimes of the exposed individuals. Thus, to see excess cancers in the county-wide annual cancer statistics, the collective dose would have to be substantially more than ten times but less than 80 times larger. If the collective dose was distributed over the 702 people living within the Surry Co. portion of the 5 mi-area, the average individual dose would be several hundred rem, or on the order of 10 rem/year if spread over an assumed 28.5 year release period.⁵ The exposures to people living closer to the plant would be even greater. It is not credible to assume that such high radioactive releases would have gone undetected.

Similarly, across the James River in James City Co., there are 3,320 people within 5 miles of the Surry Nuclear Power Station. Here the collective dose required to produce the 10.6 cancer deaths (the upper 95% confidence interval for this county) is 18,900 person-rem. If this collective dose was distributed over the 3,320 people living within James City Co. portion of the 5 mi-area, the average individual dose would be still be over 100 rem, or several rem/year if spread over the assumed 28.5 year release period. Again, it is not credible that the releases needed to cause this level of exposure would have gone undetected.

Of course, one could go through this same exercise for the each of the other plant sites, but the conclusion would be the same. One could also examine specific types of cancer, each sex separately, and different ethnic groups, and attempt to control for economic and environmental factor, but in doing so the statistics will become less robust. For example, the upper 95% confidence interval for leukemia in James City Co. is 3.2 cancer deaths/year, 30% of the 10.6 cancer deaths/year for all cancer sites. However, the leukemia cancer risk is 6 leukemia deaths/100,000 person-rem, which is about 10.5% of the total cancer death risk. The collective dose required to produce the 3.2 leukemia deaths is 53,300 person-rem, almost three times the collective dose needed to produce the annual cancer death confidence interval for all cancer sites. Thus, we do not believe examining specific cancer types will change our findings.

In sum, we believe use of county-wide cancer mortality statistics in ecologic studies is not a fruitful way to assess potential cancers due to routine releases of radioactive emissions from U.S. nuclear power plants.⁶ If mortality data collected by states and counties on a less than county-wide basis is used, the statistics will be less robust and accounting for the movement of people in and out of the area around the plants will become a more important factor.

Consequently, we do not see utility in conducting ecologic studies—epidemiological studies using county-wide, or less than county-wide, cancer mortality data—of populations near U.S. nuclear power plants for the purpose of assessing the extent to which routine emissions have caused excess cancers. In any case a better approach for allaying concerns of local citizens

⁵ Here we have assumed radioactive releases from the plant began when the first reactor at the site achieved criticality and continued through 2007 minus an assumed 5 year latency period.

⁶ An ecologic study evaluates the relationship of an exposure and a disease at the population level rather than the individual. The 1990 NCI study that the NRC has used so far to communicate the health effects of living near a nuclear plant was an ecologic study of mortality.

regarding risk from exposure to radioactive emissions from the power plants would be to provide comprehensive continuous radiation monitoring around nuclear power plants and have the recorded data publically accessible on the web in real time.

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Table 1. 2010 population around U.S. nuclear plants by county.

Site	County, State	2010 Population within 5 Miles	2010 Population within 10 Miles
Arkansas Nuclear One	Johnson County, Arkansas	56	1,599
Arkansas Nuclear One	Logan County, Arkansas	169	967
Arkansas Nuclear One	Pope County, Arkansas	9,795	38,510
Arkansas Nuclear One	Yell County, Arkansas	1,457	5,712
Beaver Valley Power Station	Allegheny County, Pennsylvania		16
Beaver Valley Power Station	Beaver County, Pennsylvania	14,001	86,768
Beaver Valley Power Station	Columbiana County, Ohio	289	21,557
Beaver Valley Power Station	Hancock County, West Virginia	212	8,300
Beaver Valley Power Station	Washington County, Pennsylvania		4
Braidwood Generating Station	Grundy County, Illinois	8,990	16,251
Braidwood Generating Station	Kankakee County, Illinois	316	2,217
Braidwood Generating Station	Livingston County, Illinois		19
Braidwood Generating Station	Will County, Illinois	9,968	18,996
Browns Ferry Nuclear Plant	Lauderdale County, Alabama	544	227
Browns Ferry Nuclear Plant	Lawrence County, Alabama		5,439
Browns Ferry Nuclear Plant	Limestone County, Alabama	2,463	17,194
Browns Ferry Nuclear Plant	Morgan County, Alabama	237	13,131
Brunswick Steam Electric Plant	Brunswick County, North Carolina	8,642	21,476
Brunswick Steam Electric Plant	New Hanover County, North Carolina	80	6,789
Byron Generating Station	Ogle County, Illinois	10,030	27,291
Byron Generating Station	Winnebago County, Illinois		699
Callaway Nuclear Power Station	Callaway County, Missouri	1,164	8,130
Callaway Nuclear Power Station	Gasconade County, Missouri		34
Callaway Nuclear Power Station	Montgomery County, Missouri		258
Callaway Nuclear Power Station	Osage County, Missouri	10	962
Calvert Cliffs Nuclear Power Station	Calvert County, Maryland	12,271	26,503
Calvert Cliffs Nuclear Power Station	Dorchester County, Maryland		139
Calvert Cliffs Nuclear Power Station	St. Mary's County, Maryland		9,202
Catawba Nuclear Station	Gaston County, North Carolina		6,633
Catawba Nuclear Station	Lancaster County, South Carolina		1,777
Catawba Nuclear Station	Mecklenburg County, North Carolina	5,102	45,069
Catawba Nuclear Station	York County, South Carolina	37,003	167,155
Clinton Power Station	De Witt County, Illinois	1,024	11,767
Clinton Power Station	Macon County, Illinois		409
Clinton Power Station	McLean County, Illinois		338
Clinton Power Station	Piatt County, Illinois		260
Comanche Peak Steam Electric Station	Hood County, Texas	2,207	26,328

Comanche Peak Steam Electric Station	Johnson County, Texas		1
Comanche Peak Steam Electric Station	Somervell County, Texas	3,455	7,466
Cook (Donald C.) Nuclear Power Station	Berrien County, Michigan	15,033	52,320
Cooper Nuclear Station	Atchison County, Missouri	389	1,526
Cooper Nuclear Station	Holt County, Missouri		9
Cooper Nuclear Station	Nemaha County, Nebraska	302	1,926
Cooper Nuclear Station	Richardson County, Nebraska		226
Crystal River Nuclear Power Station	Citrus County, Florida	3,208	17,619
Crystal River Nuclear Power Station	Levy County, Florida	34	2,714
Davis-Besse Nuclear Power Station	Lucas County, Ohio	2	290
Davis-Besse Nuclear Power Station	Ottawa County, Ohio	2,614	15,186
Davis-Besse Nuclear Power Station	Sandusky County, Ohio		57
Diablo Canyon Nuclear Power Plant	San Luis Obispo County, California	295	22,927
Dresden Generating Station	Grundy County, Illinois	14,442	42,589
Dresden Generating Station	Kendall County, Illinois		3,600
Dresden Generating Station	Will County, Illinois		14,704
Duane Arnold Energy Center	Benton County, Iowa	757	4,739
Duane Arnold Energy Center	Linn County, Iowa	8,481	107,886
Enrico Fermi Atomic Power Plant	Monroe County, Michigan	14,580	69,430
Enrico Fermi Atomic Power Plant	Wayne County, Michigan		20,742
Fort Calhoun Station	Douglas County, Nebraska		901
Fort Calhoun Station	Harrison County, Iowa	271	2,051
Fort Calhoun Station	Pottawattamie County, Iowa	45	351
Fort Calhoun Station	Washington County, Nebraska	8,141	16,072
Grand Gulf Nuclear Station	Claiborne County, Mississippi	1,990	6,947
Grand Gulf Nuclear Station	Jefferson County, Mississippi		1
Grand Gulf Nuclear Station	Madison Parish, Louisiana		7
Grand Gulf Nuclear Station	Tensas Parish, Louisiana	149	1,222
Grand Gulf Nuclear Station	Warren County, Mississippi		233
H.B. Robinson Nuclear Power Station	Chesterfield County, South Carolina	640	3,178
H.B. Robinson Nuclear Power Station	Darlington County, South Carolina	13,792	27,652
H.B. Robinson Nuclear Power Station	Kershaw County, South Carolina		326
H.B. Robinson Nuclear Power Station	Lee County, South Carolina	92	1,348
Hanford Reservation	Benton County, Washington	0	1,499
Hanford Reservation	Franklin County, Washington	238	2,712
Hatch (Edwin I.) Nuclear Power Station	Appling County, Georgia	1,428	5,181
Hatch (Edwin I.) Nuclear Power Station	Jeff Davis County, Georgia		1,128
Hatch (Edwin I.) Nuclear Power Station	Montgomery County, Georgia		129
Hatch (Edwin I.) Nuclear Power Station	Tattnall County, Georgia		908
Hatch (Edwin I.) Nuclear Power Station	Toombs County, Georgia	624	2,805
Indian Point Nuclear Power Station	Orange County, New York	1,204	17,177

Indian Point Nuclear Power Station	Putnam County, New York	1,016	12,485
Indian Point Nuclear Power Station	Rockland County, New York	25,259	95,498
Indian Point Nuclear Power Station	Westchester County, New York	47,204	129,967
James A. FitzPatrick Nuclear Power Plant	Oswego County, New York	3,996	31,647
Joseph M. Farley Nuclear Plant	Early County, Georgia	427	2,205
Joseph M. Farley Nuclear Plant	Henry County, Alabama		493
Joseph M. Farley Nuclear Plant	Houston County, Alabama	1,537	8,694
Kewaunee Nuclear Power Station	Kewaunee County, Wisconsin	843	5,854
Kewaunee Nuclear Power Station	Manitowoc County, Wisconsin	766	4,172
La Salle County Generating Station	Grundy County, Illinois	55	1,418
La Salle County Generating Station	La Salle County, Illinois	2,125	14,925
La Salle County Generating Station	Livingston County, Illinois		13
Limerick Generating Station	Berks County, Pennsylvania		24,079
Limerick Generating Station	Chester County, Pennsylvania	21,953	69,734
Limerick Generating Station	Montgomery County, Pennsylvania	68,170	152,525
McGuire (W.B.) Nuclear Station	Cabarrus County, North Carolina		24
McGuire (W.B.) Nuclear Station	Catawba County, North Carolina		2,207
McGuire (W.B.) Nuclear Station	Gaston County, North Carolina	1,294	17,062
McGuire (W.B.) Nuclear Station	Iredell County, North Carolina	572	14,136
McGuire (W.B.) Nuclear Station	Lincoln County, North Carolina	10,054	24,510
McGuire (W.B.) Nuclear Station	Mecklenburg County, North Carolina	33,595	132,276
Millstone Nuclear Power Station	Middlesex County, Connecticut		447
Millstone Nuclear Power Station	New London County, Connecticut	39,462	100,401
Millstone Nuclear Power Station	Suffolk County, New York		326
Monticello Nuclear Generating Plant	Sherburne County, Minnesota	9,967	29,475
Monticello Nuclear Generating Plant	Wright County, Minnesota	12,105	29,693
Nine Mile Point Nuclear Station	Oswego County, New York	4,143	32,000
North Anna Nuclear Power Station	Caroline County, Virginia		136
North Anna Nuclear Power Station	Hanover County, Virginia		573
North Anna Nuclear Power Station	Louisa County, Virginia	2,872	10,046
North Anna Nuclear Power Station	Orange County, Virginia		188
North Anna Nuclear Power Station	Spotsylvania County, Virginia	2,872	12,367
Oconee Nuclear Power Station	Oconee County, South Carolina	6,181	37,403
Oconee Nuclear Power Station	Pickens County, South Carolina	4,406	37,662
Oyster Creek Generating Station	Ocean County, New Jersey	42,472	122,661
Palisades Nuclear Power Station	Allegan County, Michigan		1,006
Palisades Nuclear Power Station	Berrien County, Michigan		11,201
Palisades Nuclear Power Station	Van Buren County, Michigan	5,736	19,108
Palo Verde Nuclear Power Station	Maricopa County, Arizona	770	3,928
Peach Bottom Atomic Power Station	Cecil County, Maryland	421	6,525
Peach Bottom Atomic Power Station	Chester County, Pennsylvania		444

Peach Bottom Atomic Power Station	Harford County, Maryland	1,731	12,116
Peach Bottom Atomic Power Station	Lancaster County, Pennsylvania	3,138	16,996
Peach Bottom Atomic Power Station	York County, Pennsylvania	3,857	10,116
Perry Nuclear Power Plant	Ashtabula County, Ohio		4,755
Perry Nuclear Power Plant	Geauga County, Ohio		1,275
Perry Nuclear Power Plant	Lake County, Ohio	21,421	76,395
Pilgrim Nuclear Station	Barnstable County, Massachusetts		263
Pilgrim Nuclear Station	Plymouth County, Massachusetts	16,668	65,636
Point Beach Nuclear Power Station	Kewaunee County, Wisconsin	160	1,818
Point Beach Nuclear Power Station	Manitowoc County, Wisconsin	1,843	18,623
Prairie Island Nuclear Generating Plant	Dakota County, Minnesota	2	2,569
Prairie Island Nuclear Generating Plant	Goodhue County, Minnesota	2,526	19,294
Prairie Island Nuclear Generating Plant	Pierce County, Wisconsin	1,096	7,786
Quad Cities Generating Station	Clinton County, Iowa	2,313	19,344
Quad Cities Generating Station	Rock Island County, Illinois	1,165	3,681
Quad Cities Generating Station	Scott County, Iowa	995	6,547
Quad Cities Generating Station	Whiteside County, Illinois	117	2,164
River Bend Station	East Baton Rouge Parish, Louisiana		3,313
River Bend Station	East Feliciana Parish, Louisiana	314	4,963
River Bend Station	Pointe Coupee Parish, Louisiana	952	8,327
River Bend Station	West Baton Rouge Parish, Louisiana		204
River Bend Station	West Feliciana Parish, Louisiana	3,107	7,181
Robert E. Ginna Nuclear Power Station	Monroe County, New York	1,664	35,411
Robert E. Ginna Nuclear Power Station	Wayne County, New York	9,530	26,241
Salem and Hope Creek Generating Stations	Cumberland County, New Jersey		1,077
Salem and Hope Creek Generating Stations	Kent County, Delaware		777
Salem and Hope Creek Generating Stations	New Castle County, Delaware	2,943	29,230
Salem and Hope Creek Generating Stations	Salem County, New Jersey	908	12,060
San Onofre Nuclear Generating Station	Orange County, California	11,516	70,243
San Onofre Nuclear Generating Station	Riverside County, California		3
San Onofre Nuclear Generating Station	San Diego County, California	5,221	16,031
Seabrook Nuclear Station	Essex County, Massachusetts	13,092	53,671
Seabrook Nuclear Station	Rockingham County, New Hampshire	26,437	63,789
Sequoyah Nuclear Power Station	Bradley County, Tennessee		5,839
Sequoyah Nuclear Power Station	Hamilton County, Tennessee	27,317	89,746
Sequoyah Nuclear Power Station	Meigs County, Tennessee		116
Shearon Harris Nuclear Power Plant	Chatham County, North Carolina	989	6,844
Shearon Harris Nuclear Power Plant	Harnett County, North Carolina	90	3,731
Shearon Harris Nuclear Power Plant	Lee County, North Carolina		2,848
Shearon Harris Nuclear Power Plant	Wake County, North Carolina	7,538	78,513

South Texas Project Electric Generating Station	Matagorda County, Texas	475	2,241
St. Lucie Nuclear Power Station	Martin County, Florida		19,495
St. Lucie Nuclear Power Station	St. Lucie County, Florida	22,510	163,575
Surry Nuclear Power Station	Isle of Wight County, Virginia	131	901
Surry Nuclear Power Station	James City County, Virginia	3,320	32,286
Surry Nuclear Power Station	Newport News city, Virginia	144	59,431
Surry Nuclear Power Station	Surry County, Virginia	702	2,380
Surry Nuclear Power Station	Williamsburg city, Virginia		13,316
Surry Nuclear Power Station	York County, Virginia		9,516
Susquehanna Steam Electric Station	Columbia County, Pennsylvania	1,852	17,111
Susquehanna Steam Electric Station	Luzerne County, Pennsylvania	10,409	36,256
Three Mile Island Generating Station	Cumberland County, Pennsylvania		2,407
Three Mile Island Generating Station	Dauphin County, Pennsylvania	12,212	73,447
Three Mile Island Generating Station	Lancaster County, Pennsylvania	5,307	34,768
Three Mile Island Generating Station	Lebanon County, Pennsylvania		121
Three Mile Island Generating Station	York County, Pennsylvania	20,867	73,089
Turkey Point Power Station	Miami-Dade County, Florida	5,699	157,456
Turkey Point Power Station	Monroe County, Florida		51
Vermont Yankee Generating Station	Cheshire County, New Hampshire	5,025	12,030
Vermont Yankee Generating Station	Franklin County, Massachusetts	93	5,364
Vermont Yankee Generating Station	Windham County, Vermont	10,098	17,069
Virgil C. Summer Nuclear Power Station	Fairfield County, South Carolina	1,143	4,283
Virgil C. Summer Nuclear Power Station	Lexington County, South Carolina		1,392
Virgil C. Summer Nuclear Power Station	Newberry County, South Carolina	739	4,189
Virgil C. Summer Nuclear Power Station	Richland County, South Carolina	117	2,493
Vogtle (Alvin W.) Nuclear Power Station	Aiken County, South Carolina	22	646
Vogtle (Alvin W.) Nuclear Power Station	Allendale County, South Carolina		9
Vogtle (Alvin W.) Nuclear Power Station	Barnwell County, South Carolina	182	616
Vogtle (Alvin W.) Nuclear Power Station	Burke County, Georgia	967	3,624
Vogtle (Alvin W.) Nuclear Power Station	Richmond County, Georgia		310
Waterford Generating Station	Lafourche Parish, Louisiana		75
Waterford Generating Station	St. Charles Parish, Louisiana	7,926	40,831
Waterford Generating Station	St. John the Baptist Parish, Louisiana	6,859	46,280
Watts Bar Nuclear Power Station	McMinn County, Tennessee		2,679
Watts Bar Nuclear Power Station	Meigs County, Tennessee	2,552	7,143
Watts Bar Nuclear Power Station	Rhea County, Tennessee	2,952	10,119
Watts Bar Nuclear Power Station	Roane County, Tennessee		32
Wolf Creek Generating Station	Anderson County, Kansas		16
Wolf Creek Generating Station	Coffey County, Kansas	1,558	4,975
Sum		861,020	3,926,983

Table 2. Age adjusted cancer death rates for the period 2003-2007 in counties where nuclear plants are located. <http://statecancerprofiles.cancer.gov/cgi-bin/deathrates/deathrates.pl?05&001&00&0&001&1&1&1>

Site Name	Reactor Units	State	County	Cancer Deaths/100,000
Arkansas Nuclear One	2	Arkansas	Pope	182.9 (167.9, 198.8)
Beaver Valley Power Station	2	Pennsylvania	Beaver	192.7 (184.9, 200.7)
Braidwood Generating Station	2	Illinois	Will	194.2 (188.3, 200.1)
Browns Ferry Nuclear Plant	3	Alabama	Limestone	200.1 (185.2, 215.8)
Brunswick Steam Electric Plant	2	North Carolina	Brunswick	190.4 (179.2, 202.2)
Byron Generating Station	2	Illinois	Ogle	182.0 (167.1, 198.0)
Callaway Nuclear Power Station	1	Missouri	Callaway	182.6 (164.1, 202.6)
Calvert Cliffs Nuclear Power Station	2	Maryland	Calvert	215.4 (200.1, 231.5)
Catawba Nuclear Station	2	South Carolina	York	202.7 (193.3, 212.5)
Clinton Power Station	1	Illinois	DeWitt	213.9 (186.5, 244.5)
Columbia Generating Station	1	Washington	Benton	188.2 (178.1, 198.7)
Comanche Peak Steam Electric Station	2	Texas	Somervell	166.8 (130.2, 210.9)
Cook (Donald C.) Nuclear Power Station	2	Michigan	Berrien	193.9 (185.1, 202.9)
Cooper Nuclear Station	1	Nebraska	Nemaha	153.1 (119.5, 194.3)
Crystal River Nuclear Power Station	1	Florida	Citrus	201.8 (193.7, 210.3)
Davis-Besse Nuclear Power Station	1	Ohio	Ottawa	214.2 (197.1, 232.6)
Diablo Canyon Nuclear Power Plant	2	California	San Luis Obispo	165.7 (159.2, 172.5)
Dresden Generating Station	2	Illinois	Grundy	203.8 (184.7, 224.4)
Duane Arnold Energy Center	1	Iowa	Linn	178.1 (170.0, 186.4)
Enrico Fermi Atomic Power Plant	1	Michigan	Monroe	197.9 (187.8, 208.3)
Fort Calhoun Station	1	Nebraska	Washington	178.1 (153.6, 205.4)
Grand Gulf Nuclear Station	1	Mississippi	Claiborne	222.1 (182.1, 268.2)
H.B. Robinson Nuclear Power Station	1	South Carolina	Darlington	221.8 (206.5, 237.9)
Hatch (Edwin I.) Nuclear Power Station	2	Georgia	Appling	201.2 (172.4, 233.4)
Indian Point Nuclear Power Station	2	New York	Westchester	164.3 (160.9, 167.8)
Joseph M. Farley Nuclear Plant	2	Alabama	Houston	193.5 (181.9, 205.8)
Kewaunee Nuclear Power Station	1	Wisconsin	Kewaunee	169.7 (147.4, 194.5)
La Salle County Generating Station	2	Illinois	LaSalle	213.0 (202.2, 224.2)
Limerick Generating Station	2	Pennsylvania	Montgomery	179.2 (175.3, 183.1)
McGuire (W.B.) Nuclear Station	2	North Carolina	Mecklenburg	179.3 (174.5, 184.3)
Millstone Nuclear Power Station	2	Connecticut	New London	188.6 (181.5, 195.9)

Monticello Nuclear Generating Plant	1	Minnesota	Wright	182.5 (169.4, 196.4)
Nine Mile Point & James A. FitzPatrick Nuclear Stations	3	New York	Oswego	209.9 (198.4, 222.0)
North Anna Nuclear Power Station	2	Virginia	Louisa	197.3 (176.4, 220.1)
Oconee Nuclear Power Station	3	South Carolina	Oconee	173.2 (161.1, 186.1)
Oyster Creek Generating Station	1	New Jersey	Ocean	202.0 (197.6, 206.5)
Palisades Nuclear Power Station	1	Michigan	Van Buren	198.1 (184.6, 212.5)
Palo Verde Nuclear Power Station	3	Arizona	Maricopa	156.9 (155.0, 158.8)
Peach Bottom Atomic Power Station	2	Pennsylvania	York	180.6 (175.1, 186.3)
Perry Nuclear Power Plant	1	Ohio	Lake	201.2 (193.7, 208.9)
Pilgrim Nuclear Station	1	Massachusetts	Plymouth	200.5 (194.9, 206.2)
Point Beach Nuclear Power Station	2	Wisconsin	Manitowoc	165.7 (154.7, 177.4)
Prairie Island Nuclear Generating Plant	2	Minnesota	Goodhue	172.7 (157.5, 189.1)
Quad Cities Generating Station	2	Illinois	Rock Island	179.8 (171.1, 188.9)
River Bend Station	1	Louisiana	West Feliciana	214.6 (177.7, 256.9)
Robert E. Ginna Nuclear Power Station	1	New York	Wayne	187.4 (175.5, 200.0)
Salem and Hope Creek Generating Stations	3	New Jersey	Salem	209.8 (195.3, 225.1)
San Onofre Nuclear Generating Station	2	California	San Diego	172.5 (170.3, 174.7)
Seabrook Nuclear Station	1	New Hampshire	Rockingham	193.7 (186.4, 201.3)
Sequoyah Nuclear Power Station	2	Tennessee	Hamilton	191.8 (185.5, 198.2)
Shearon Harris Nuclear Power Plant	1	North Carolina	Wake	172.4 (167.3, 177.7)
South Texas Project Electric Generating Station	2	Texas	Matagorda	209.9 (190.1, 231.2)
St. Lucie Nuclear Power Station	2	Florida	St Lucie	181.4 (175.0, 188.1)
Surry Nuclear Power Station	2	Virginia	Surry	202.4 (160.2, 252.8)
Susquehanna Steam Electric Station	2	Pennsylvania	Luzerne	197.3 (191.4, 203.3)
Three Mile Island Generating Station	1	Pennsylvania	Dauphin	190.8 (183.7, 198.1)
Turkey Point Power Station	2	Florida	Miami-Dade	149.9 (147.8, 152.0)
Vermont Yankee Generating Station	1	Vermont	Windham	183.2 (167.1, 200.5)
Virgil C. Summer Nuclear Power Station	1	South Carolina	Fairfield	227.4 (202.2, 254.9)
Vogtle (Alvin W.) Nuclear Power Station	2	Georgia	Burke	237.6 (208.4, 269.6)
Waterford Generating Station	1	Louisiana	St. Charles	197.1 (178.4, 217.2)
Watts Bar Nuclear Power Station	1	Tennessee	Rhea	218.6 (196.7, 242.3)
Wolf Creek Generating Station	1	Kansas	Coffey	247.4 (206.5, 294.6)
United States				183.8 (183.6, 184.0)

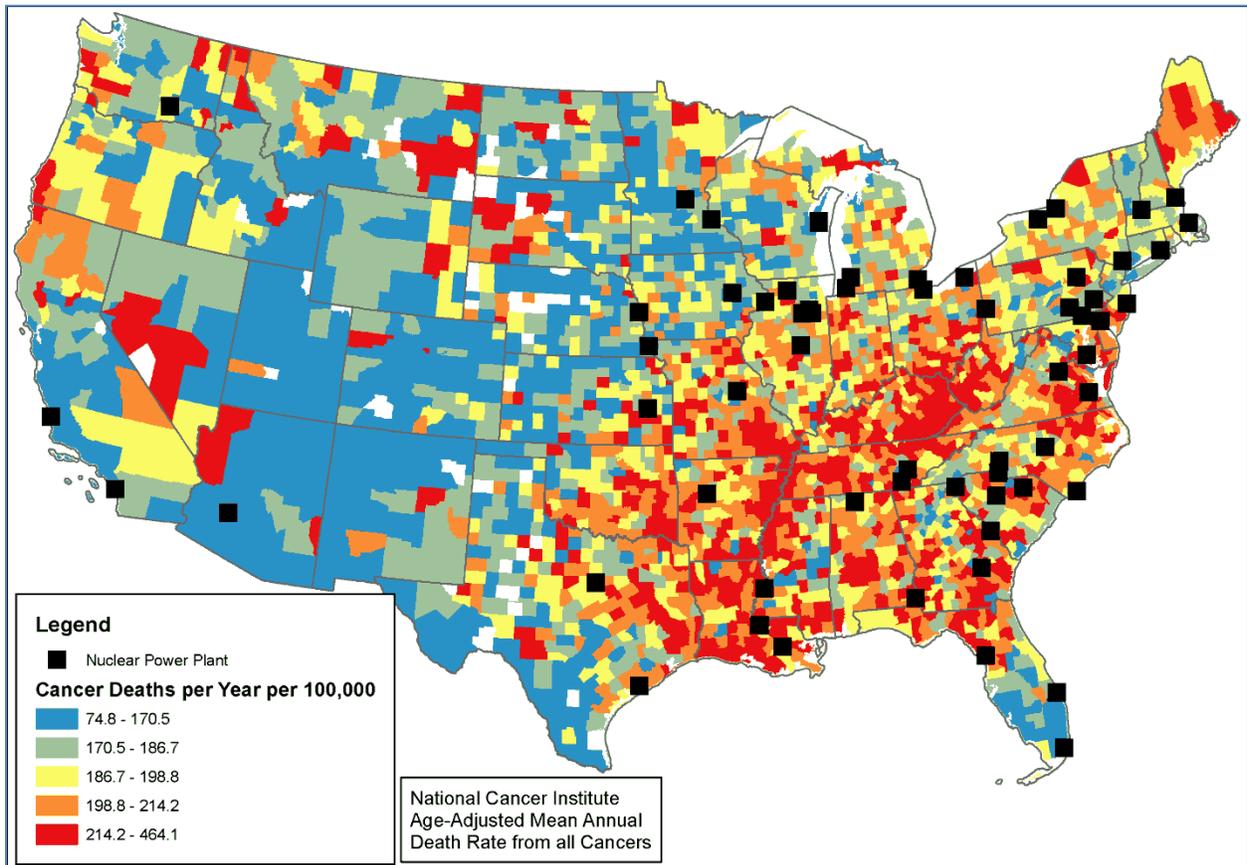


Figure 1. Age adjusted mean annual cancer death rate per 100,000 persons by U.S. county for the period 2003-2007.

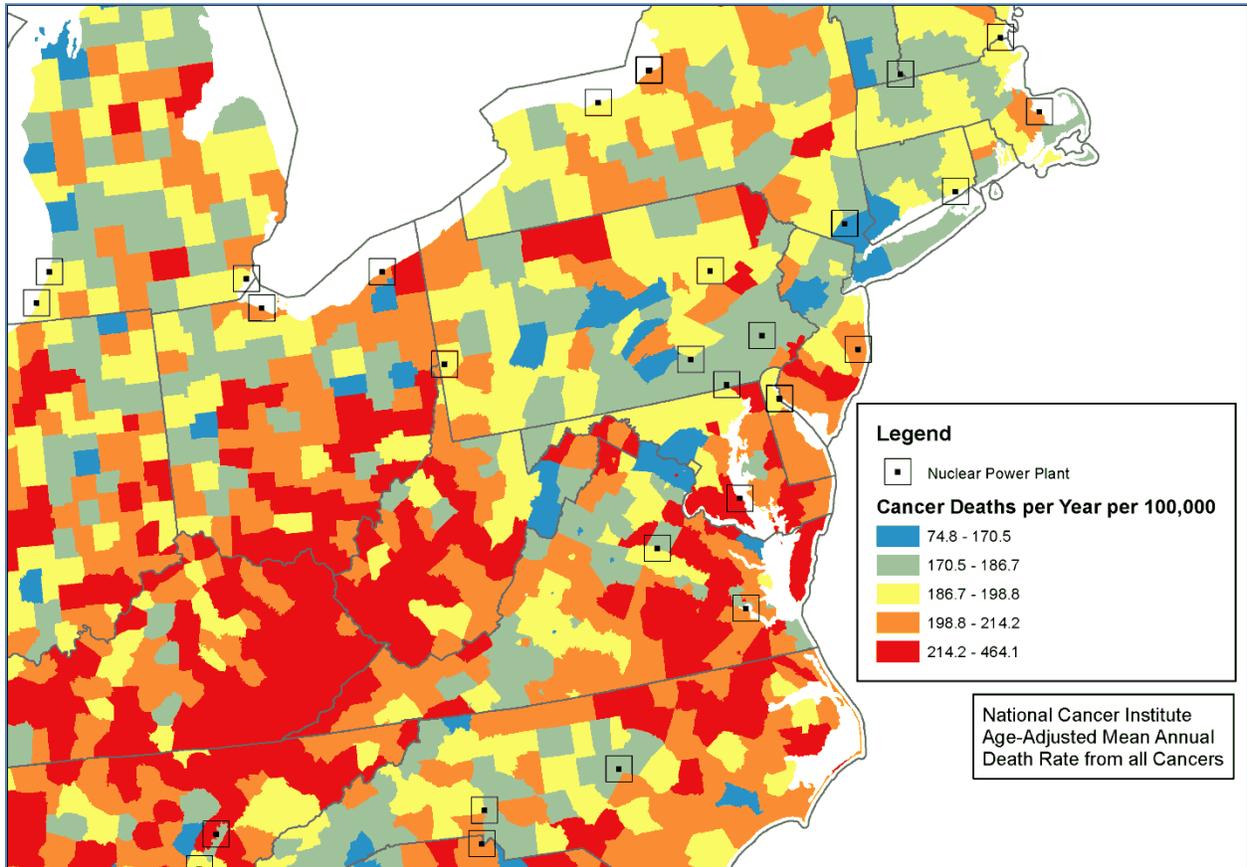


Figure 2. Age adjusted mean annual cancer death rate per 100,000 persons by county (northeast U.S.) for the period 2003-2007.

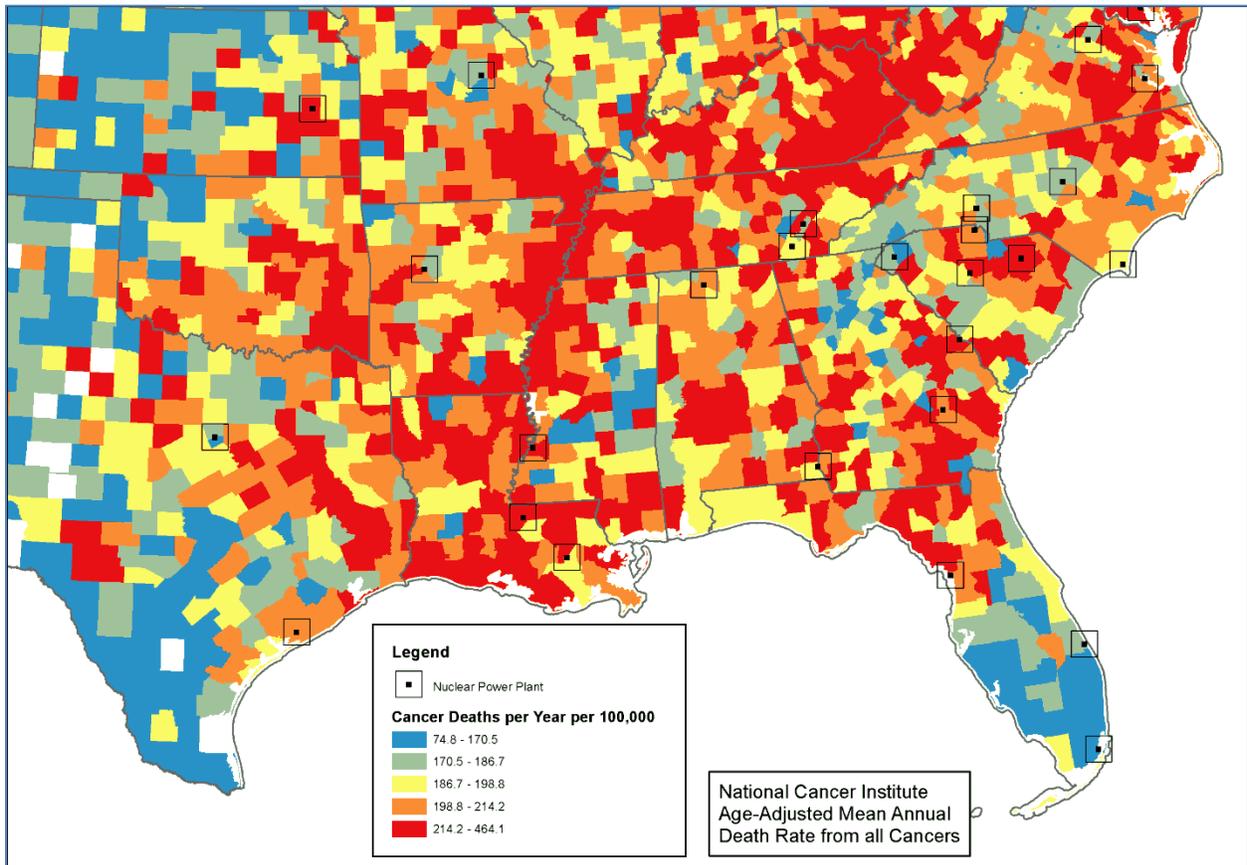


Figure 3. Age adjusted mean annual cancer death rate per 100,000 persons by county (southeast U.S.) for the period 2003-2007.

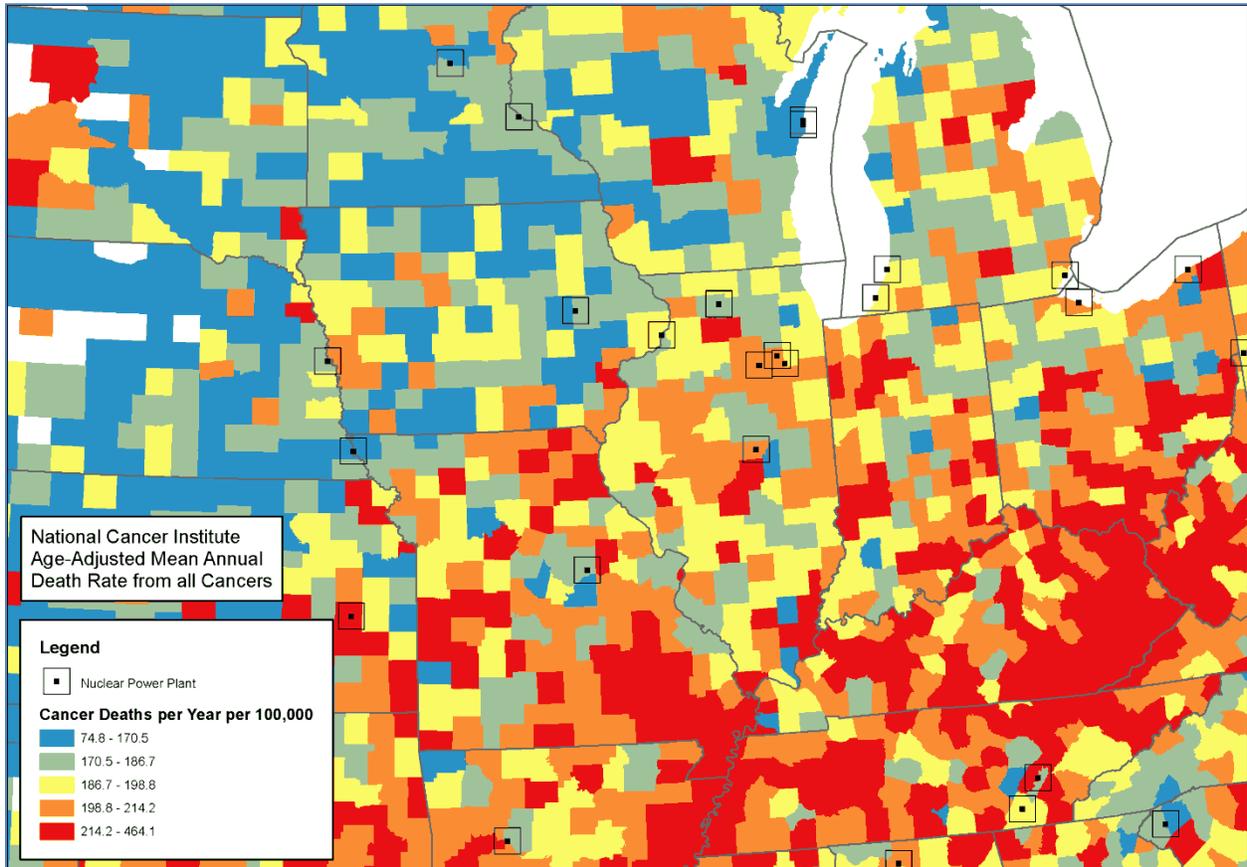


Figure 4. Age adjusted mean annual cancer death rate per 100,000 persons by county (midwest U.S.) for the period 2003-2007.

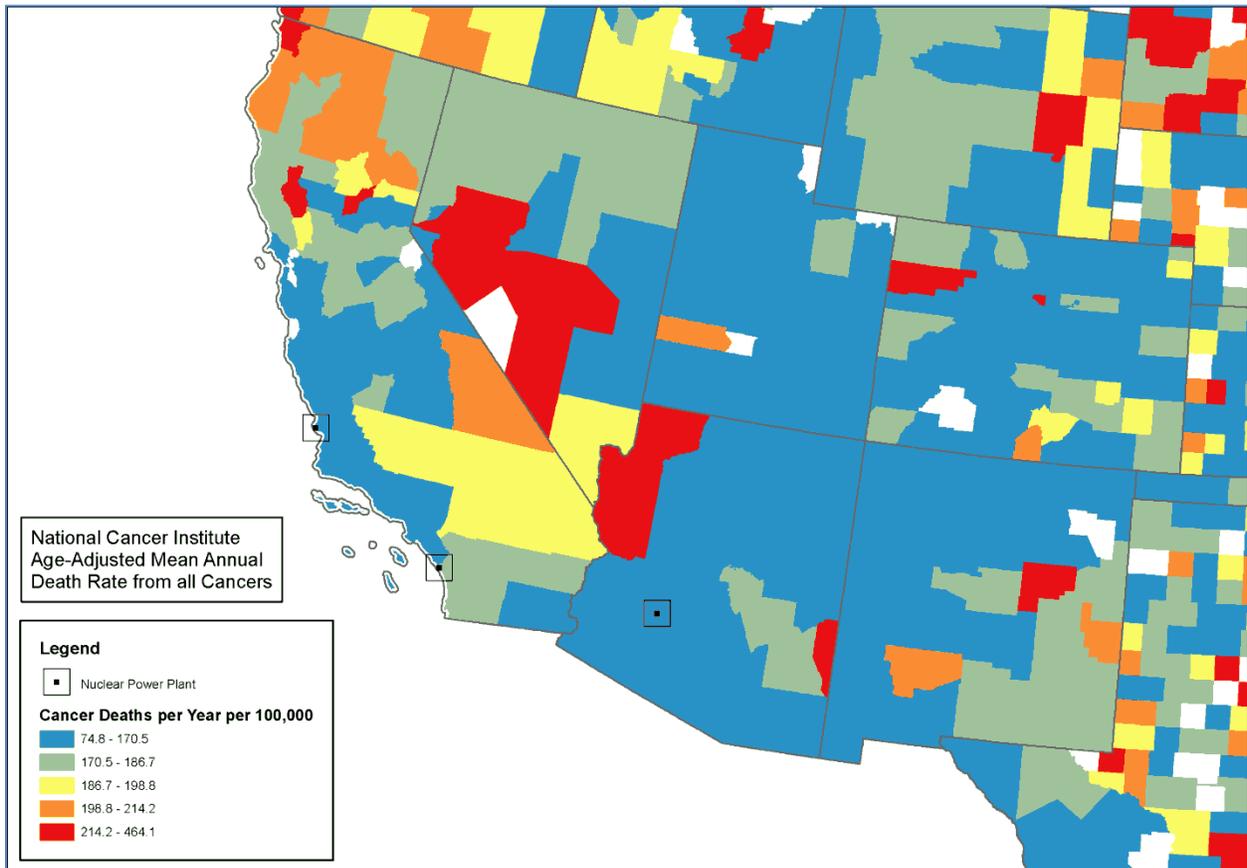


Figure 5. Age adjusted mean annual cancer death rate per 100,000 persons by county (southwest U.S.) for the period 2003-2007.

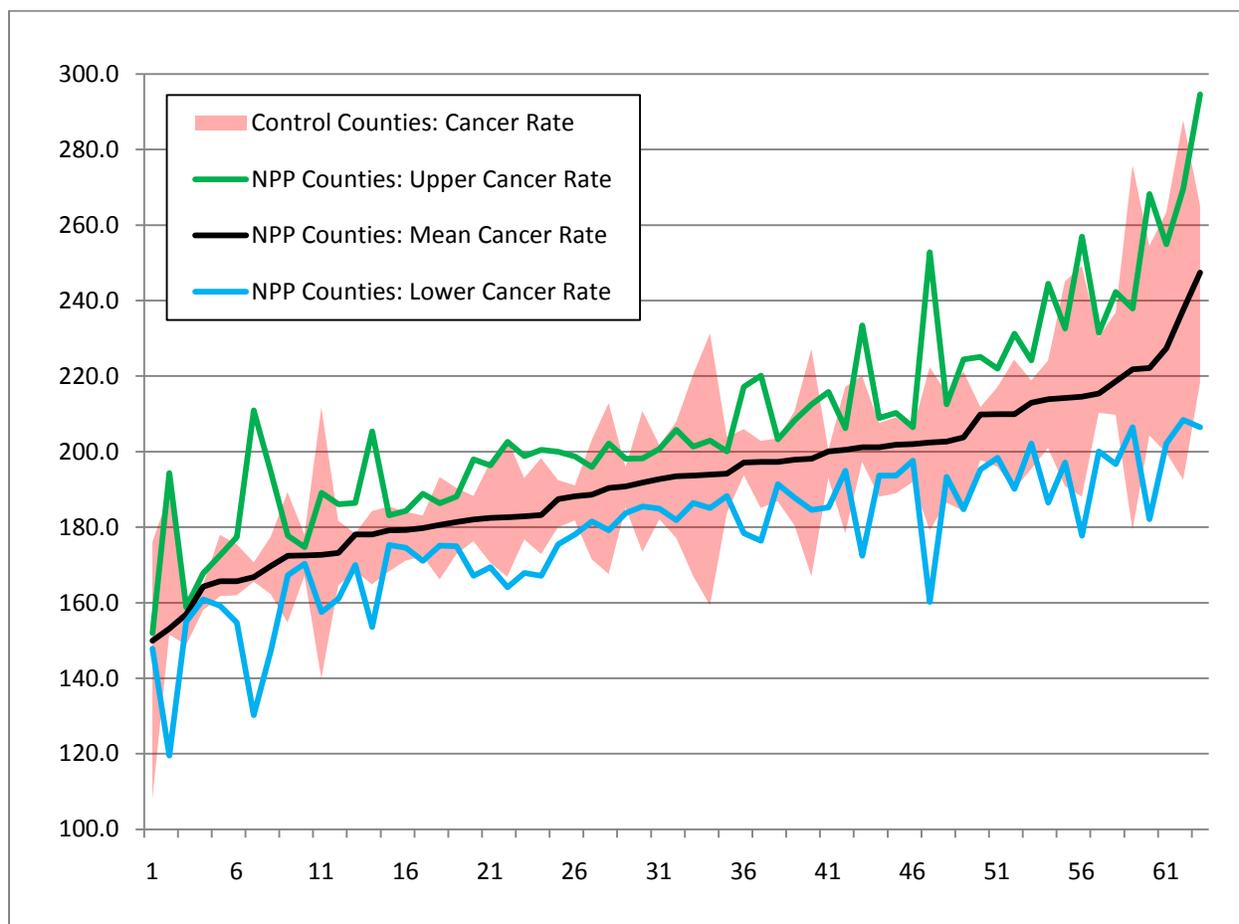


Figure 6. Rank-ordered age adjusted annual cancer death rates (mean and 95% confidence limits) for 63 counties where nuclear plants are located superimposed upon the 95% confidence limit band for 63 control counties having similar populations. Ordinate is cancer death/year per 100,000 persons averaged over the period 2003-2007.

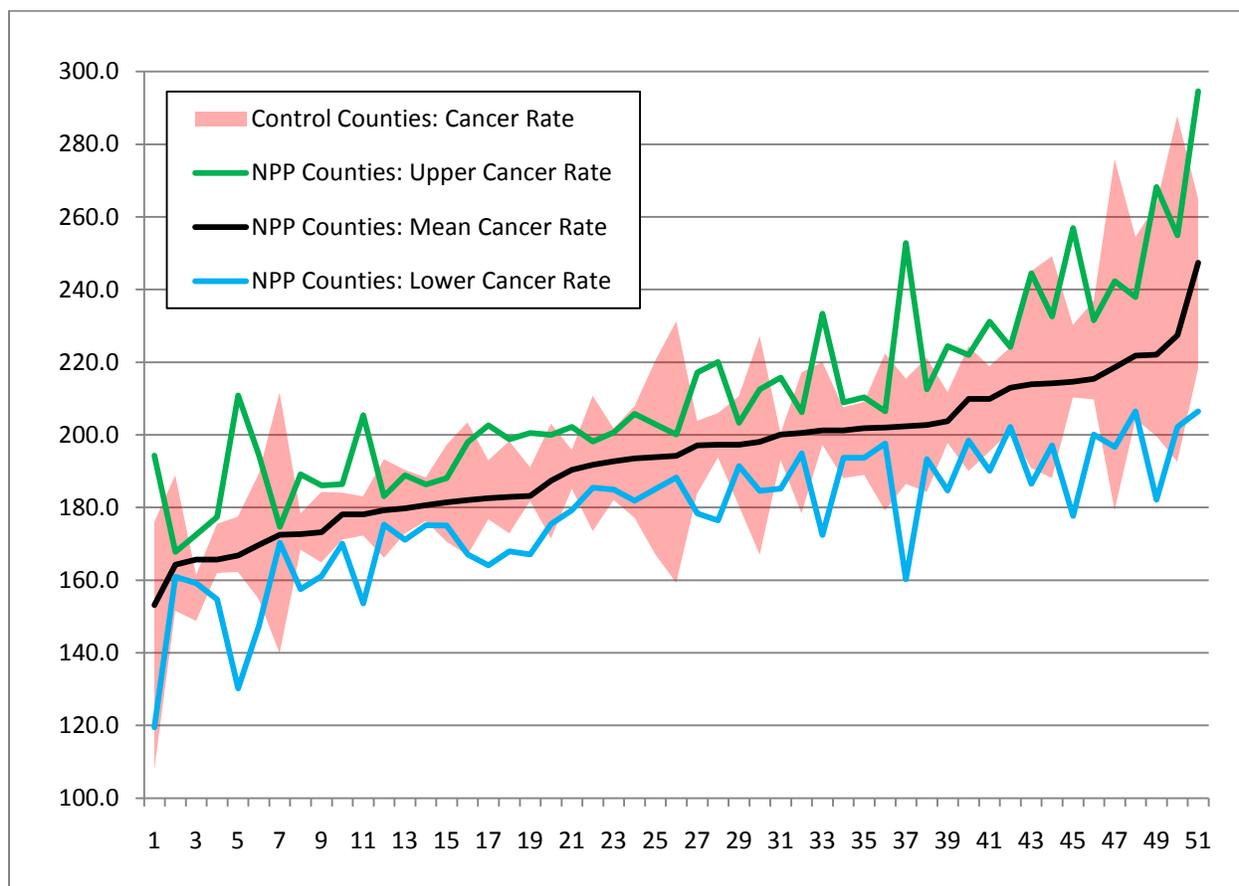


Figure 7. Rank-ordered age adjusted annual cancer death rates (mean and 95% confidence limits) for 51 counties where nuclear plants are located superimposed upon the 95% confidence limit band for 51 control counties having similar populations. Ordinate is cancer death/year per 100,000 persons averaged over the period 2003-2007.