GEOGRAPHIC VARIATION IN U.S. THYROID CANCER INCIDENCE, AND A CLUSTER NEAR NUCLEAR REACTORS IN NEW JERSEY, NEW YORK, AND PENNSYLVANIA

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Thyroid cancer incidence is increasing more rapidly than any other malignancy in the U.S. (along with liver cancer), rising nearly threefold from 1980 to 2006. Improved diagnosis has been proposed as the major reason for this change by some, while others contend that other factors also account for the increase. Among U.S. states, 2001-2005 age-adjusted thyroid cancer incidence rates vary from 5.4 to 12.8 per 100,000. County-specific incidence data available for the first time document that most U.S. counties with the highest thyroid cancer incidence are in a contiguous area of eastern Pennsylvania, New Jersey, and southern New York. Exposure to radioactive iodine emissions from 16 nuclear power reactors within a 90 mile radius in this area as a potential etiological factor of thyroid cancer is explored; these emissions are likely a cause of rising incidence rates.

From 1980 to 2006, annual U.S. thyroid cancer incidence rose nearly threefold, from 4.33 to 11.03 cases per 100,000 (age adjusted to the 2000 U.S. standard population). This increase has been steady, rising in 22 of 26 years, and has been most pronounced since the early 1990s (1). Along with liver/bile duct cancer, incidence of thyroid cancer has experienced the greatest increase of any type of malignancy (Appendix 1). Temporal trends during this period were consistent (between +137% and +181%) for males, females, blacks, and whites. Rates have risen markedly for all age groups except for children and the very old (Appendix 2). The expected annual number of newly diagnosed U.S. thyroid cancer cases has reached 37,340. Improvements in treatment have raised survival rates; by 2006, the prevalence of U.S. thyroid cancer survivors was 410,404, and is increasing by more than 20,000 each year. (1)

This significant and largely unexpected rise in U.S. thyroid cancer incidence is consistent with reports of similar increases in many other developed nations, including Scotland, France, Italy, the Netherlands, Poland, the Czech Republic, Switzerland, Australia, England, Wales, and Canada. (2-11) A recent study concluded that the rise in U.S. thyroid cancer incidence is a function of improved diagnostic techniques, especially for papillary malignancies, which account for the large majority of thyroid cancer cases. (12) Another report contradicts this conclusion, contending that improved detection only accounts for a portion of the increase, and other factors should be explored. (13)

A frequently-employed means of understanding reasons for disease patterns is that of geographic variation. Studies of U.S. cancer incidence and mortality at the state, county, congressional district, and state economic area levels have been made. (14-17) “Cancer mapping” techniques can be useful in generating etiological hypotheses. (18) While variations in cancer rates are often due to risk factors, screening rates, and effectiveness of treatments, some conclude that cancer is often caused by environmental factors. (19)

The first national U.S. cancer incidence data base can be particularly helpful in studying low-incidence cancers with relatively low mortality rates. (20-21) Thyroid cancer is relatively uncommon (2-3% of incident cases in the U.S.) and has one of the highest survival rates of any cancer, making mortality data of little use.

There have been few attempts to assess geographic differences in thyroid cancer incidence. However, at least two reports have documented a wide variation between nations. (22-23) One of these (23) cited the many studies that document sensitivity of the thyroid gland to radiation-induced oncogenesis from exposure to radioiodine isotopes. Affected populations include survivors of the Hiroshima and Nagasaki atomic bombs and Nevada, Semlja, and Marshall Island bomb tests, along with the Chernobyl accident.

The purpose of this report is to compare thyroid cancer incidence rates across U.S. states and counties, to identify any potential causes of rapid rises in the past several decades.

MATERIALS AND METHODS

Collection of U.S. cancer cases has been a function historically performed by state governments. Until the 1990s, most of the 50 states had either no established registry or voluntary reporting that failed to produce useful data. But the emergence of comprehensive registries in all 50 states, plus efforts by the U.S. government to establish a unified data base makes geographic analysis possible.

Recently, the U.S. Centers for Disease Control and Prevention compiled state-based cancer incidence data for all states plus the District of Columbia from 2001-2005, excluding only Maryland, Mississippi, Tennessee, Virginia, and Wisconsin. The data base also includes county-specific data for all states, excluding the five mentioned above plus Illinois, Minnesota, North Dakota, and the Colorado counties of Adams, Boulder, Broomfield, Jefferson, and Weld. Incidence rates are published only for those counties with at least 15 thyroid cancer cases diagnosed in 2001-2005, as rates in less-populated counties are based on small numbers of cases which are often not reliable.

This report will utilize the following data:

1. State thyroid cancer incidence for 45 states plus the District of Columbia, representing about 276 million Americans (90.7% of the 2008 U.S. population of 304 million).

2. County-specific thyroid cancer incidence for 42 states plus the District of Columbia for the one-fifth (628) of the 3139 U.S. counties with a 2008 population over 88,000, with a total of 241 million Americans (79.4%) are analyzed. In states with county-specific data, 500 of these counties, with 202 million (66.6% of the U.S.) are analyzed (Appendix 3).

Rates are calculated as the annual number of thyroid cancer cases per 100,000 persons, adjusted to the 2000 U.S. standard population for 2001-2005. The number of cases diagnosed in this period, plus confidence intervals (to the 95% level), are also provided.

RESULTS

For 2001-2005, the U.S. thyroid cancer rate was 8.9 per 100,000, adjusted to the 2000 U.S. standard population. Each state had at least 250 cases in the five-year period. Rates ranged from 5.4 in Arkansas (n = 755, CI = 5.0-5.8) to 12.8 in Pennsylvania (n = 8330, CI = 12.6-13.1) (Table 1). Of the seven states with the highest rates, five are in the northeast U.S. (Pennsylvania, Massachusetts, New Jersey, Connecticut, and Rhode Island). Of the five states with the lowest rates, four are in the southeast U.S. (Arkansas, North Carolina, Alabama, and South Carolina).

Table 1
Thyroid Cancer Incidence, by State, U.S., 2001-2005 (U.S. Rate = 8.9, CI = 8.9-9.0)

State	Cases per 100000 (n), CI		State	Cases per 100000 (n), CI	
1. Pennsylvania	12.8 (8330)	12.6-13.1	26. Florida	8.6 (7825)	8.4- 8.8
2. New Mexico	12.1 (1125)	11.4-12.9	26. Missouri	8.6 (2485)	8.2- 8.9
3. Massachusetts	12.0 (4000)	11.6-12.4	26. New Hampshire	8.6 (575)	7.9- 9.3
4. Utah	11.9 (1215)	11.2-12.6	29. Kentucky	8.4 (1780)	8.1- 8.9
5. New Jersey	11.8 (5260)	11.5-12.1	29. South Dakota	8.4 (320)	7.5- 9.4
6. Connecticut	11.7 (2110)	11.2-12.2	29. West Virginia	8.4 (825)	7.8- 9.0
7. Rhode Island	11.3 (625)	10.5-12.3	32. Michigan	8.3 (4205)	8.0- 8.5
8. Montana	10.9 (515)	10.0-11.9	32. Texas	8.3 (---)	8.1- 8.5
9. Delaware	10.8 (450)	9.8-11.8	34. Minnesota	8.2 (2095)	7.9- 8.6
9. Nevada	10.8 (1245)	10.2-11.5	35. California	8.0 (13645)	7.8- 8.1
9. Wyoming	10.8 (275)	9.6-12.2	35. North Dakota	8.0 (255)	7.1- 9.1
12. Hawaii	10.6 (680)	9.8-11.4	37. Indiana	7.8 (2420)	7.5- 8.1
13. Idaho	10.4 (690)	9.6- 11.2	37. Oregon	7.8 (1425)	7.4- 8.2
13. New York	10.4 (10255)	10.2-10.6	39. Ohio	7.6 (4440)	7.4- 7.8
15. Kansas	9.9 (1340)	9.4-10.5	40. Louisiana	7.5 (---)	7.1- 7.9
16. Arizona	9.8 (2685)	9.4- 10.1	41. Georgia	7.3 (3135)	7.1- 7.6
17. Colorado	9.7 (2200)	9.3-10.1	42. North Carolina	6.7 (2865)	6.4- 6.9
18. Iowa	9.4 (1405)	8.9-10.0	42. South Carolina	6.7 (1415)	6.3- 7.0
18. Nebraska	9.4 (815)	8.8- 10.1	44. Alabama	6.4 (---)	6.1- 6.8
20. Vermont	9.3 (300)	8.2- 10.4	45. Oklahoma	5.9 (1035)	5.5- 6.3
20. Washington	9.3 (2905)	9.0- 9.7	46. Arkansas	5.4 (755)	5.0- 5.8
22. Alaska	9.2 (295)	8.1-10.4	Maryland	No data available	
23. Dist. of Columbia	9.0 (270)	8.0-10.2	Mississippi	No data available	
24. Illinois	9.0 (5650)	8.3- 9.2	Tennessee	No data available	
25. Maine	9.0 (615)	8.3- 9.8	Virginia	No data available	
			Wisconsin	No data available	

Source: U.S. Centers for Disease Control and Prevention, http://statecancerprofiles.cancer.gov, Rates adjusted to 2000 U.S. standard population. Cases calculated from annual cases in 2001-2005. The 45 states plus District of Columbia with computed rates account for 90.7% of U.S. population. Rates, but not case numbers, given for Alabama, Louisiana, and Texas.

No obvious demographic factors explain these variations. For example, Pennsylvania has the highest state rate for all races and genders (12.8 cases per 100,000 population, or 44% above the U.S.). However, its rates exceed the U.S. for whites (+40%), blacks (+63%), Asian/Pacific Islanders (+26%), males (+28%) and females (+47%).

Table 2 lists the 18 U.S. counties with the highest 2001-2005 thyroid cancer incidence, of the 500 U.S. counties with over 88,000 residents. Rankings for all races and whites, which account for nearly 90% of U.S. thyroid cancer cases, are given.

Table 2
Counties with Highest Thyroid Cancer Incidence Rate
500 U.S. Counties with Population > 88,000, 43 States, All Races, 2001-2005

U.S. Rank All	U.S. Rank White	County	2008 Pop.	Cases	Cases per 100,000 Pop.	95% CI
1	1	*Lehigh PA	339,989	360	21.4	19.2- 23.7
2	2	Cache UT	112,616	65	19.0	14.6 – 24.4
3	4	*Northampton PA	294,787	275	18.8	16.6 – 21.2
4	3	*Rockland NY	298,545	265	18.3	16.1 – 20.6
5	5	*Putnam NY	99,244	95	18.0	14.4 – 22.1
6	6	*Luzerne PA	311,893	300	17.6	15.6 – 19.7
7	8	*York PA	424,583	360	17.1	15.4 – 19.0
8	7	*Orange NY	379,647	295	16.6	14.7 – 18.6
8	9	Lubbock TX	264,418	---	16.6	14.1 - 19.2
10	15	Lawrence PA	90,272	80	16.5	13.0 – 20.6
11	11	Bonneville ID	99,135	65	16.4	12.6 – 20.9
12	13	Delaware IN	114,685	98	16.3	13.1 - 20.0
13	16	Yellowstone MT	142,348	110	16.1	13.2 – 19.4
14	19	Mercer PA	116,652	100	15.8	12.8 – 19.3
14	18	*Bucks PA	621,643	515	15.8	14.4 – 17.2
16	11	*Camden NJ	517,234	410	15.7	14.2 – 17.3
17	16	*Burlington NJ	445,475	360	15.5	13.9 – 17.2
18	21	*Lancaster PA	502,370	370	15.3	13.8 – 17.0

* Within 90 miles of 40^{o} 20’ north latitude, 75^{o} 20’ west longitude.

Source: U.S. Centers for Disease Control and Prevention, http://statecancerprofiles.cancer.gov. Rates adjusted to 2000 U.S. standard population. Cases calculated from annual cases in 2001-2005. The 500 counties represent 66.6% of U.S. population. Excluded are IL, MD, MN, MS, ND, TN, VA, and WI plus Adams CO, Boulder CO, Jefferson CO, and Weld CO. Rate, but not case numbers, given for Alabama, Louisiana, and Texas.

Thirteen (13) of the 18 counties with the highest rates for all races combined are from the contiguous states of New Jersey, New York, and Pennsylvania. Moreover, 11 of these counties lie within 90 miles of 40^{o} 20’ north latitude, 75^{o} 20’ west longitude (Figure 1). This area has 16 nuclear power reactors, 13 of which are still operating, at seven plants (Appendix 4). No area of the U.S. has as great a concentration of reactors.

The medical literature contains few studies of thyroid cancer incidence near U.S. nuclear installations. The National Cancer Institute examined cancer mortality near 62 plants, but included incidence data for only four sites. The NCI typically selected the counties completely or mostly within 20 miles of a nuclear plant for study. Incidence ratios for thyroid cancer in these counties rose after startup for each of four areas (Table 3).

Table 3
Thyroid Cancer Incidence Rate in Counties Closest to Nuclear Plants
Before and After Reactor Startup, Connecticut and Iowa, 1950-1984

Nuclear Plant	Bef/Aft Startup	Standard Incidence Ratio (Cases) Before Startup	After Startup	Change
Haddam Neck CT	1950-67 1968-84	0.94 (36)	1.03 (76)	+ 9
Millstone CT	1950-70 1971-84	0.69 (64)	0.79 (90)	+10
Duane Arnold IA	1969-74 1975-84	0.92 (23)	1.13 (77)	+21
Ft. Calhoun IA	1969-73 1974-84	0.52 (1)	0.92 (6)	+40
TOTAL		0.785 (124)	0.950 (249)	+16.5 p<.05

Source: Jablon S et al. Cancer in Populations Living Near Nuclear Facilities. National Cancer Institute, NIH Pub. No. 90-874. Washington DC: U.S. Government Printing Office, 1990. Rates adjusted to 1970 U.S. standard population. Counties included are Middlesex CT (Haddam Neck), New London CT (Millstone), Benton/Linn IA (Duane Arnold), Harrison IA (Ft. Calhoun).

The observation that the most elevated thyroid cancer rates in the U.S. are in an area with many nuclear reactors raises the question of whether proximity to these plants raises thyroid cancer risk. Table 4 displays thyroid cancer rates for counties in the New Jersey/southern New York/eastern Pennsylvania area within 20 miles of a nuclear plant.

Table 4
Thyroid Cancer Incidence Rate, Counties within 20 Miles of a Nuclear Plant
All Races, New Jersey, Southern New York, Eastern Pennsylvania, 2001-2005

County/State	2008 Pop.	Cases	Cases per 100,000 Pop.	95% CI
Indian Point (Buchanan NY)				
Orange NY	379,647	295	16.6	14.7 – 18.6
Putnam NY	99,244	95	18.0	14.4 – 22.1
Rockland NY	298,545	265	18.3	16.1 – 20.6
Westchester NY	953,943	620	12.6	11.6 - 13.6
Oyster Creek (Forked River NJ)				
Ocean NJ	569,111	415	14.1	12.7 – 15.6
Salem/Hope Creek (Salem NJ)				
New Castle DE	529,641	320	12.3	11.0 - 13.8
Salem NJ	65,910	40	10.9	7.7 – 15.0
Limerick (Pottstown PA)				
Chester PA	491,489	325	13.7	12.2 – 15.2
Montgomery PA	778,048	565	13.9	12.8 – 15.1
Peach Bottom (Delta PA)				
Lancaster PA	502,370	370	15.3	13.8 – 17.0
Susquehanna (Berwick PA)				
Columbia PA	64,818	30	8.9	6.0 – 12.8
Luzerne PA	311,893	300	17.6	15.6 – 19.7
Three Mile Island (Londonderry PA)				
Lebanon PA	128,934	80	12.8	10.1 - 15.9
Dauphin PA	256,562	160	12.0	10.2 – 14.0
York PA	424,583	360	17.1	15.4 – 19.0

Source: U.S. Centers for Disease Control and Prevention, http://statecancerprofiles.cancer.gov, Rates adjusted to 2000 U.S. standard population. Cases calculated from annual cases in 2001-2005.

The thyroid cancer rate exceeded the U.S. rate of 8.9 per 100,000 for all of the 15 counties near nuclear plants except one (the rate for Columbia County PA was equal to the U.S.). Of particular interest are the four counties closest to the Indian Point plant, 35 miles north of New York City. Virtually all of its 1.73 million residents live within 20 miles of the plant; of its three reactors, two are operating and one has closed permanently.

In 2001-2005, 1265 residents of these four counties were diagnosed with thyroid cancer. Rates for three of the four counties (Rockland, Putnam, and Orange) ranked 4th, 5th, and

8th highest of the 500 U.S. counties in 43 states with available data with 88,000 or more residents (Table 2). Incidence in the other county (Westchester) is also well above the U.S. The large population allows incidence to be divided into age, gender, and race categories, each with significant cases. Table 5 displays 2001-2005 rates for the four counties combined near Indian Point compared to the other 58 New York counties. Rates from 1976-1980 to 2001-2005 are also provided, as the New York State Department of Health has operated a comprehensive cancer registry for over three decades.

Table 5
Thyroid Cancer Cases per 100,000 Persons
Four Counties Proximate to Indian Point Nuclear Plant
Compared to Other 58 Counties in New York State
By Gender, Age, and Race, 2001-2005

Category	Orange, Putnam Rockland, West.	Oth. NYS	% 4 Counties vs. Oth. NYS	95% CI
White Non-Hispanic	16.47 (1007)	11.30 (6534)	+45.7*	16.38-16.56
White	15.17 (1092)	10.64 (7252)	+42.6*	15.09-15.25
Black	6.95 (71)	5.67 (835)	+22.6	6.66 – 7.24
Hispanic	10.22 (99)	7.16 (856)	+42.7*	9.94- 10.50
Male	7.62 (316)	5.22 (2189)	+46.0*	7.46- 7.78
Female	21.27 (960)	14.38 (6770)	+47.9*	21.18-21.36
Age 0-24	1.95 (57)	1.70 (501)	+14.7	1.65 – 2.25
Age 25-44	18.91 (452)	12.13 (3138)	+55.9*	18.77-19.05
Age 45-64	26.43 (560)	17.42 (3629)	+51.7*	26.30-26.56
Age 65+	19.54 (207)	14.85 (1691)	+31.6*	19.36-19.72
Males				
1976-1980	2.35 (73)	2.34 (802)	+ 0.4	2.12- 2.58
1981-1985	2.97 (95)	2.35 (832)	+26.3	2.72- 3.22
1986-1990	2.99 (103)	2.52 (889)	+18.7	2.76- 3.22
1991-1995	3.30 (118)	2.99 (1125)	+10.4	3.10- 3.50
1996-2000	5.14 (198)	3.95 (1569)	+28.8	4.96- 5.32
2001-2005	7.62 (316)	5.22 (2189)	+46.0	7.46- 7.78
Females				
1976-1980	4.42 (164)	4.63 (1944)	- 4.5	4.27- 4.57
1981-1985	5.39 (208)	5.11 (2176)	+ 5.5	5.25- 5.53
1986-1990	5.97 (242)	5.30 (2303)	+12.6	5.63- 6.11
1991-1995	7.61 (317)	7.13 (3197)	+ 6.7	7.49- 7.73
1996-2000	13.71 (591)	10.22 (4666)	+34.1	13.60-13.82
2001-2005	21.27 (960)	14.38 (6770)	+47.9	21.18-21.36

Source: New York State Cancer Registry, New York State Department of Health, by special request, April 10, 2009. Rates adjusted to 2000 U.S. standard population.

The data show that in 2001-2005, local thyroid cancer rates near Indian Point significantly exceeded those for the rest of New York State, for nearly all sub-groups. Local rates were 46.0% and 47.9% higher for males and females; 42.6%, 22.6%, 42.7%, and 45.7% higher for whites, blacks, Hispanics, and white non-Hispanics; and 14.7%, 55.9%, 51.7%, and 31.6% higher for persons age 0-24, 25-44, 45-64, and over 65, respectively. Local rates for all ten categories differ significantly from rates in other New York State counties, except for blacks and persons age 0-24.

Perhaps the most revealing data in Table 5 is the temporal trend in thyroid cancer incidence near Indian Point. In the late 1970s, the local age-adjusted rate was roughly similar to that of all other New York State counties (+0.4% for males and -4.5% for females). For each five-year period since, with the exception of the early 1990s, the gap between local and state rates has widened, until the current excesses of +46.0% and +47.9% were reached.

DISCUSSION

The first data base of cancer incidence covering nearly all 50 U.S. states has documented a wide range of rates of thyroid malignancies by state in 2001-2005. Pennsylvania has the highest rate (12.8), while Arkansas has the lowest rate (5.4). The states with the highest rates tend to be in the northeast and most of those with the lowest rates are in the southeast. More specifically, 11 of the 18 counties (population over 88,000) with the highest rates are clustered in a relatively small area of New Jersey, southern New York, and eastern Pennsylvania. This area, which encompasses a 90-mile radius, has 16 nuclear power reactors at seven plants, the greatest concentration of reactors in the U.S.

Using the methodology followed by the National Cancer Institute in a large scale study of cancer near nuclear plants, 2001-2005 thyroid cancer incidence in the 15 counties all or mostly within 20 miles of the seven plants showed that all but one had rates higher than the U.S., often considerably higher (the other county had a rate equal to the U.S.).

Special consideration is given to the four counties closest to the Indian Point nuclear plant, which is located in the most densely populated region of the U.S. (35 miles from the center of New York City). The four counties are suburban rather than urban, but still are densely populated (1.73 million in 2008).

In three of the four counties, thyroid cancer incidence was about twice the U.S. rate, and ranked 4^{th}, 5^{th}, and 8^{th} highest among the 500 U.S. counties with populations of 88,000 or greater. (The rate for the fourth county, Westchester, was more than 40% above the U.S). The four-county rate significantly exceeded the U.S. for nearly all ages, races, and genders. Perhaps most importantly, there has been a gradual widening in the divergence between the local and state rates during the past three decades (they were equal in the late 1970s). The extent to which radioactive emissions, which include iodine, has contributed to this gap should be addressed in future review.

Geographic variations in mortality and incidence have been frequently used to reveal etiological factors for diseases. This report addresses the largely unexamined topic of geographic variation in U.S. thyroid cancer incidence and has identified proximity to nuclear plants as the most evident etiological factor. This finding is consistent with data in the U.S. National Cancer Institute study of cancer near nuclear plants, which documented consistent rises in thyroid cancer incidence in counties closest to nuclear plants after startup. Data in this report suggests that exposure to radioactive iodine released from nuclear plants is a factor in elevated and rapidly rising thyroid cancer rates.

Other sources of radioactive iodine exposure to Americans may also raise thyroid cancer risk, and deserve examination.

1. Atmospheric U.S. Nuclear Weapons Tests. Prior to the startup of nuclear reactors, the largest source of radioiodine exposure to Americans was from 1946-1963 atmospheric nuclear weapons tests from 1946-1963, before such tests were banned. The U.S. conducted 206 atmospheric tests during this time, 100 in the western state of Nevada and 106 in the south Pacific. (24) In particular, the Nevada tests released radioactive fission products into the stratosphere, which drifted across the continental U.S. and returned to the environment via precipitation.

The National Cancer Institute estimated Iodine-131 uptake from Nevada tests and estimated thyroid cancer risk for each U.S. county, by date of birth, gender, and amount and type of milk consumed. (25) These I-131 estimates were the basis for a projection that 11,300 to 212,000 Americans (central projection of 49,000) would develop thyroid cancer from exposure to I-131 in Nevada bomb test fallout. (26)

A detailed examination of the relationship between I-131 doses from Nevada tests current thyroid cancer rates by county would be unwieldy. But a cursory review suggests that latent effects of exposure to bomb fallout cannot explain the geographic variations documented in this report because:

- Some states with the greatest exposures have the lowest thyroid cancer incidence rates in 2001-2005, e.g., Alabama and Arkansas

- Current thyroid incidence is rising sharply for those not affected by bomb fallout (born before 1932 and after 1963)

- Cases diagnosed in 2001-2005, about half a century after exposure to bomb fallout, exceed the generally-accepted latency between exposure and disease onset of 25-35 years

- With 37,340 new cases of thyroid cancer diagnosed each year in the U.S., even the higher estimate of 212,000 fallout-related thyroid cancer cases would only be a small percentage of lifetime cases

- Counties in areas near nuclear reactors in southern New York and eastern Pennsylvania (with high thyroid cancer incidence) had similar bomb fallout exposures to other counties in these states (lower thyroid cancer incidence)

2. Atmospheric Foreign Nuclear Weapons Tests. Fallout from atomic bomb tests conducted in other nations entered the U.S. environment. Exposures, the largest of which cancer from tests by the Soviet Union from late 1961-late 1962 were much than those from the U.S. Nevada tests. (27) Thus, these exposures to I-131 would explain very little, if any, of the current geographic variations in thyroid cancer.

3. Head and Neck Irradiation. Another possible explanation for rising thyroid cancer rates is latent effects of high dose therapeutic head and neck irradiation for various benign diseases, which has been linked to the disease. Such irradiation ended in the 1950s, and the latency between exposure and onset of disease has been estimated at between 25 and 35 years. (28-29) Thyroid cancer diagnosed in the period 2001-2005 is likely beyond the latency period between exposure to this therapeutic irradiation and manifestation of disease.

4. Chernobyl. Another source of radioactive iodine in the U.S. environment is fallout from the 1986 accident at the Chernobyl plant. During May and June 1986, levels of I-131 in U.S. milk increased about threefold before returning to typical concentrations. The highest levels, about 10-15 times the normal values, occurred in monitoring sites located in the northwestern states, including Boise Idaho, Spokane Washington, and Helena Montana. (30)

However, 2001-2005 thyroid cancer incidence in these states are not unusually high; of 46 states, Idaho is 13th highest, Washington is 20th highest, and Montana is 8th highest. This pattern, plus the fact that I-131 only existed in the U.S. diet for about two months in 1986, make it likely that radioiodine from Chernobyl had only a very modest effect in geographic variation in thyroid cancer incidence.

5. Three Mile Island. Another source of exposure to radioactive iodine, especially in the northeast U.S. is airborne emissions from the 1979 accident at the Three Mile Island plant. Official reports estimated 14.2 curies of I-131 and particulates were released into the environment, (31) and prevailing winds carried the radioactivity hundreds of miles to the east and northeast. (32-33) But the 2001-2005 thyroid cancer rate Dauphin County PA, where the reactor is located, had a rate of 12.0, lower than many other counties in the state. Again, while 1979 Three Mile Island emissions may play a factor in subsequent thyroid cancer state and county, these data suggest it is not a major contributor.

6. Iodine Generated Outside the Local Area. Another possible source of radioactive iodine is in food imported from other areas. Determining the sources of the food supply in an area, even in a single type of food such as milk, is a highly complex undertaking. The existence of pastures and dairy farms in southeastern Pennsylvania (an area with multiple nuclear reactors) which exports milk to various parts of the region, may be a

contributor to geographic variations in thyroid cancer risk, but it is not possible to calculate the extent of this risk.

Data presented in this report indicate that emissions from nuclear power reactors are likely to be a contributing factor in current U.S. thyroid cancer incidence rates. This finding merits further examination, especially in light of the fact that 104 such reactors continue to operate in the U.S. These exposures are relatively low dose, leading some to assume that there can be no effect on cancer risk at these doses. But there is a precedent of revisionism for this assumption; for decades, officials declared levels of atomic bomb fallout to be so low as to not affect cancer risk. The two official reports of the 1ate 1990s ended this assumption, by calculating I-131 uptake and converting it to an estimated 11,300–212,000 lifetime cases of thyroid cancer among Americans from fallout. (25) (26)

In the case of Indian Point, there is some data on I-131 emissions and environmental levels. From 1970-1993, Indian Point released 17.50 curies of airborne I-131 and particulates, the highest amount of any U.S. nuclear plant except for Dresden IL (97.22), Oyster Creek NJ (77.05), Millstone CT (32.80), and Quad Cities IL (26.95). The amount exceeded the official total of 14.20 curies released from the 1979 Three Mile Island accident. (31) In 2007, officials that operate the Indian Point plant reported levels of I-131 in the local air, water, and milk, each of which is a potential vector for ingestion. (34)

Future study should make all due effort to establishing exposure levels, by state and county, of radioactive iodine, a task made difficult by the multiple vectors of ingestion (air, water, food) and the combination of local and distant sources of iodine isotopes. Other potential co-factors that might affect cancer risk, including demographics, life style patterns, and use of medical services, should be studied as well. Despite these challenges, careful attention should be paid to results in this report, especially as rapidly rising thyroid cancer rates in the U.S. and other nations remain unexplained.

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Appendix 1
Change in Incidence Rates by Type of Cancer, U.S.
Invasive Cancers Only, 1980-2006

Cancer	Cases per 100,000 1980	Cases per 100,000 2006	% Change
Liver and Bile Duct	2.62	6.69	+155.3
Thyroid	4.33	11.03	+154.7
Melanoma of the Skin	10.50	21.14	+101.3
Kaposi Sarcoma	0.28	0.55	+ 96.4
Kidney and Renal Pelvis	8.06	13.90	+ 72.5
Non-Hodgkin's Lymphoma	12.61	19.52	+ 54.8
Prostate	105.99	163.06	+ 53.8
Testis	4.35	5.52	+ 26.9
Female Breast	102.19	123.04	+ 20.4
Myeloma	5.02	5.37	+ 6.9
Esophagus	4.27	4.56	+ 6.8
Hodgkin's Lympoma	2.77	2.93	+ 5.8
Pancreas	11.52	12.01	+ 4.3
Urinary Bladder	20.42	20.46	+ 0.2
Lung and Bronchus	60.65	59.97	- 1.1
Brain and Other Nervous System	6.29	6.12	- 2.7
Mesothelioma	0.98	0.93	- 5.1
Leukemia	12.91	11.89	- 7.9
Corpus Uteri	27.31	24.08	- 12.0
Ovary	15.44	12.48	- 19.2
Oral Cavity and Pharynx	13.34	10.29	- 22.9
Colon and Rectum	63.74	45.45	- 28.7
Larynx	5.25	3.24	- 38.3
Stomach	11.29	7.34	- 35.0
Cervix Uteri	12.23	6.72	- 45.1
All Cancers	417.94	456.20	+ 9.2

Source: Cancer Statistics Review, from Surveillance, Epidemiology, and End Results (SEER), www.cancer.seer.gov. Covers states of CT, HI, IA, NM, and UT, and metropolitan areas of Atlanta, Detroit San Francisco, and Seattle (representing about 10% of U.S. population). Rates adjusted to 2000 U.S. standard population.

Appendix 2
Change in Thyroid Cancer Incidence by Age at Diagnosis
U.S., 1984-1988 vs. 1998-2002

Age at Diagnosis	Year of Birth 1984-88	Year of Birth 1998-02	Cases per 100,000 1984-88	Cases per 100,000 1998-02	% Change Rate '84-88 to '98-02
0- 4	1980-88	1994-02	0.0	0.0	----
5- 9	1975-83	1989-97	0.0	0.0	----
10-14	1970-78	1984-92	0.4	0.5	+25.0
15-19	1965-73	1979-87	1.5	2.0	+33.3
20-24	1960-68	1974-82	3.2	4.5	+40.6
25-29	1955-63	1969-77	4.4	7.6	+72.7
30-34	1950-58	1964-72	6.0	9.4	+56.7
35-39	1945-53	1959-67	6.7	10.9	+62.7
40-44	1940-48	1954-62	7.2	11.6	+61.1
45-49	1935-43	1949-57	8.2	12.0	+46.3
50-54	1930-38	1944-52	7.9	13.0	+64.6
55-59	1925-33	1939-47	7.5	13.7	+82.7
60-64	1920-28	1934-42	8.2	13.3	+62.2
65-69	1915-23	1929-37	8.3	13.6	+63.9
70-74	1910-18	1924-32	8.5	11.8	+38.8
75-79	1905-13	1919-27	6.7	12.1	+80.6
80-84	1900-08	1914-22	9.0	9.8	+ 8.9
85+	pre-1900	pre-1914	6.8	7.4	+ 8.8

Source: Cancer Statistics Review, from Surveillance, Epidemiology, and End Results (SEER), www.cancer.seer.gov. Data covers states of CT, HI, IA, NM, and UT, and metropolitan areas of Atlanta, Detroit San Francisco, and Seattle (about 10% of U.S. population). After 2002, SEER expanded to 17 states and metropolitan areas.

Appendix 3
Counties Used in Thyroid Cancer Incidence Analysis

Category	No. Counties	2008 Population	% of U.S. Pop.
All U.S. counties, 50 states	3139	304,059,724	100.0
Most populated 20% of U.S. counties (>88,000)	628	241,467,475	79.4
Most populated 20% of U.S. Counties, 43 States with available cancer data	500	202,358,687	66.6

Excluded are IL, MD, MN, MS, ND, TN, VA, plus Adams CO, Boulder CO, Jefferson CO, and Weld CO.
Source: U.S. Centers for Disease Control and Prevention, http://statecancerprofiles.cancer.gov,

Appendix 4
Nuclear Power Reactors Within 100 Mile Radius
New Jersey, Southern New York, and Eastern Pennsylvania

Reactor	Location	Megawatts Electrical	Startup	Closed
1. Indian Point 1	Buchanan NY	257	8/ 2/62	10/31/74
2. Indian Point 2	Buchanan NY	951	5/22/73	
3. Indian Point 3	Buchanan NY	965	4/ 6/76	
4. Limerick 1	Limerick PA	1105	12/22/84	
5. Limerick 2	Limerick PA	1105	8/ 1/89	
6. Peach Bottom 1	Delta PA	40	3/ 3/66	10/31/74
7. Peach Bottom 2	Delta PA	1093	9/16/73	
8. Peach Bottom 3	Delta PA	1035	8/ 7/74	
9. Salem 1	Salem NJ	1106	12/11/76	
10. Salem 2	Salem NJ	1106	8/ 8/80	
11. Hope Creek	Salem NJ	1031	6/28/86	
12. Susquehanna 1	Berwick PA	1090	9/10/82	
13. Susquehanna 2	Berwick PA	1094	5/ 8/84	
14. Three Mile Island 1	Londonderry PA	786	6/ 5/74	
15. Three Mile Island 2	Londonderry PA	906	3/27/78	3/28/79
16. Oyster Creek	Forked River NJ	619	5/ 3/69	

Source: U.S. Nuclear Regulatory Commission, www.nrc.gov.