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ABSTRACT

The objective of this study was to examine childhood cancer incidence in proximity to nuclear power plants in Illinois. Cancer cases diagnosed among Illinois children 0 to 14 years old from 1986 through 2005 were included in the study. Standardized incidence ratio (SIR) was calculated for the geographic zones defined by the proximity to nuclear power plants. The results show that children living within 10 miles of any nuclear power plant did not have significant increase in incidence for leukemia (period 1986-1995: SIR=0.85 [95% confidence interval, CI: 0.54-1.26]; period 1996-2005: 1.23 [0.91-1.64]), lymphomas (period 1986-1995: 1.38 [0.77-2.27]; period 1996-2005: 0.77 [0.37-1.42]), or other cancer sites. Neither did the children living 10 to 20 miles or 20 to 30 miles from any nuclear power plants. This study did not find any significant childhood cancer excess among children living near nuclear plants and did not observe any dose-response patterns.

KEYWORDS: childhood cancer, nuclear, ionizing radiation, epidemiology, environmental

Whether children living in the vicinity of nuclear power plants have increased risk for cancer has been controversial; a number of studies have examined the risk in different countries,¹⁻⁷ but most of the studies were conducted in Europe and few of them in the United States.^{8,9} The few studies conducted in the United States often used surrounding county as surrogate exposure measure. Studies of cancer incidence among children living near nuclear power plants in the United States with a large sample size, long periods of observation, and better approximation of exposure are warranted.

Since children seem more susceptible to radiation exposure than adults, and cancers in children have relatively short latency period, many of the studies on nuclear power plants and cancer have focused on children.^{1,4,5,10,11} Childhood cancer is the most commonly used measure for evaluating health risk for persons living near nuclear installations because a given dose is proportionally larger for a fetus or child than for an adult, the fetus and young child are undergoing rapid cell growth and division during these life stages and the child undergoes increasing tissue differentiation in the maturing process.⁸ Some studies have found positive associations, but few have reached statistical significance.⁹ Although it is biologically plausible that radioisotopes emanating from air emissions from the nuclear power plants or pollution of water supplies might have adverse health effects¹² and might be absorbed by individuals living near to the plants, disagreement exists as to whether the level of exposure received by children living near nuclear sites is sufficient to result in measureable cancer risk. Radioactive discharges in the vicinity of nuclear power plants often involve very low doses, far below the level of natural background radiation. Nevertheless, the role played by exposure to low levels of ionizing

radiation in the etiology of cancer continues to cause great public concern and stimulate debate and study.¹³

Illinois ranks first among all states in the United States for the number of commercial nuclear facilities as well as the total nuclear capacity (<http://www.eia.doe.gov>). There are substantial public concerns as well as research interest regarding nuclear power plants and childhood cancer risk. The present study examined the childhood cancer incidence in relation to proximity to Illinois nuclear power plants for the periods of 1986-1995 and 1996-2005.

METHODS

Nuclear power plants in Illinois

There have been 7 nuclear power plants in Illinois, with 6 plants still in operation and 1 (Zion) that closed in 1998. The 6 operating nuclear power plants are: Braidwood, Byron, Clinton, Dresden, LaSalle, and Quad Cities (Figure 1). With the exception of the single-unit Clinton plant, each of these facilities has 2 reactors. The 2 reactors at Braidwood and both reactors at Byron are pressurized light water reactors (PWRs). The reactors at the other facilities (Clinton, Dresden, LaSalle and Quad Cities) are boiling water reactors (BWRs). In addition to the closing of Zion unit 1 and unit 2, Dresden unit 1, which began operation in 1960, was permanently shut down in 1978.

The 7 Illinois nuclear power plants are located in 7 different counties: Braidwood in Will County (reactor 1 licensed in 1987; reactor 2 in 1988), Byron in Ogle County (reactor 1 licensed in 1985;

reactor 2 in 1987), Clinton in DeWitt County (licensed in 1987), Dresden in Grundy County (reactor 2 licensed in 1970; reactor 3 in 1971), LaSalle in LaSalle County (reactor 1 licensed in 1982; reactor 2 in 1983), Quad Cities in Rock Island County (reactors 1 and 2 licensed in 1972) and Zion in Lake County (licensed in 1973 and closed in January 1998).

Distance to nuclear power plants

Distance from nuclear power plants to the ZIP Code centroid of cancer case residence was used as the surrogate of exposure. The coordinates (latitude and longitude) for the nuclear power plants were obtained from Google Earth[®]. MapInfo Professional[®] was used in geocoding Illinois ZIP Codes to produce ZIP Code centroid coordinates. We used a SAS program developed by the North American Association of Central Cancer Registries (NAACCR) for calculating great circle distances to compute distances from nuclear power plants to ZIP Code centroids. The great circle distance is the shortest distance between any 2 points on the surface of the Earth measured along a path on the surface of the Earth. The distances calculated in the NAACCR SAS program are in units of statute miles; they are estimates that assume the Earth is a sphere and ignore the effect of differences in elevation and have an error of up to about 0.5%

(www.naacr.org/filesystem/word/GreatCircleDistances3.doc). For the purposes of description and analysis, the distances were grouped into 4 geographic zones: within a radius of 10 miles (≤ 10), 10 to 20 miles (>10 and ≤ 20), 20 to 30 miles (>20 and ≤ 30), and greater than 30 miles from any nuclear power plant (Figure 1). The choice of the 10-mile increment cutoff was based on consideration of ensuring enough case numbers for each of the 4 geographic zones and consistence with the distances used in other studies.^{9, 14-16}

Cancer incidence and study population

Individual-level cancer incidence data were from the Illinois State Cancer Registry (ISCR). ISCR began collection of data on all newly diagnosed cancer cases among Illinois residents in 1986. It is the only population-based source for cancer incidence information in Illinois. Cancer cases are collected through mandated reporting by hospitals, ambulatory surgical treatment centers, non-hospital affiliated radiation therapy treatment centers, independent pathology laboratories, dermatologists, and through the voluntary exchange of cancer patient data with 11 other (mostly nearby) states. For this report, the incidence data reflect the most recent data available to ISCR as of November 2007. Using NAACCR standards for case completeness, ISCR data were estimated to have 100% completeness for the period 1996-2005 and 91% for the period 1986-1995. Due to the difference in completeness of cancer incidence data between the 2 periods, separate analysis was performed for 1986-1995 and 1996-2005.

In the present study, only cancer cases diagnosed for the period 1986-2005 for Illinois children aged 0 to 14 years were included. Pediatric cancer diagnostic groups were defined according to the scheme of the Surveillance, Epidemiology, and End Results (SEER) modified International Classification of Childhood Cancer, Third Edition (ICCC-3).¹⁷

Population data at ZIP Code level were from the United States Census 1990 and Census 2000. In Census 2000, ZIP Code Tabulation Areas (ZCTAsTM) were used as statistical geographic entities rather than the US ZIP Code service areas which were used in Census 1990. ZCTAs are generalized area representations of US Postal Service (USPS) ZIP Code service areas. In most instances the ZCTA code equals the ZIP Code for an area

<http://www.census.gov/geo/ZCTA/zcta.html>). ZIP Code populations for the period 1986-1995 (except 1990) and 1996-2005 (except 2000) were estimated using the United States Census 1990 and Census 2000 data, respectively. There were 1,232 and 1,345 ZIP Codes or ZCTAs in Illinois that had a population greater than zero in the 1990 and 2000 Census, respectively. The average population for a ZIP Code was 2,012 in the 1990 Census and 2,015 for a ZCTA in the 2000 Census.

Statistical analysis

For each geographic zone, age-adjusted standardized incidence ratios (SIRs) and 95% confidence intervals were calculated separately for the periods 1986-1995 and 1996-2005. The expected number of cases for each geographic zone was obtained using the Illinois state age-specific cancer incidence for the 2 periods and the corresponding census populations. Observed cases and the population for each zone were summed over the cases and populations from those ZIP Codes whose zip centroids fell in the zone. To further control for sex and race, we performed Poisson regression analysis for cancer sites with sufficient case counts, including leukemia, lymphomas and reticuloendothelial neoplasms, central nervous system (CNS) and miscellaneous intracranial and intraspinal neoplasms, sympathetic nervous system tumors, retinoblastoma, renal tumors, malignant bone tumors, and soft tissue sarcomas. Log-linear models were fitted on the assumption that the count of cancer cases per stratum followed a Poisson distribution. In these models, the response (dependent) variable was the count of cancer cases and the independent variable was the geographic zones used to approximate the exposure. Population count for each geographic zone was treated as offset, and age, sex and race were used as covariates. SAS PROC GENMOD was used to model Poisson regression.

SEER*Stat® software package, developed by the Information Management Services Inc. for the National Cancer Institute (NCI), was used to calculate age-specific cancer incidence rates used in estimating the expected number of cases. The rest of the statistical analyses were performed using the SAS System for Windows V9.1 (Copyright, SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA). The statistical significance level was set at .05.

RESULTS

The overall childhood cancer cases and census populations by proximity to nuclear power plants are shown in Table 1. The populations and number of cases were greater in zones that are further away from the plants as they encompass greater areas.

The observed and expected number of incidence cases by cancer site, and the standardized incidence ratios and 95% confidence intervals (CIs), for study periods 1986-1995 and 1996-2005 are presented in Table 2. Relative to the corresponding Illinois rates, children living within 10 miles of nuclear plants were not found to have a significant excess rate of leukemia (for study period 1986: SIR=0.85 [95 percent CI, 0.54-1.26]; study period 1996-2005: 1.23 [0.91-1.64], respectively), lymphomas and reticuloendothelial neoplasms (period 1986-1995: 1.38 [0.77-2.27]; period 1996-2005: 0.77 [0.37-1.42]), and of any other sites listed in Table 2. Children living within 10 to 20 miles or 20 to 30 miles from nuclear power plants did not show any increase in incidence for any cancer sites either (Table 2). In addition, any identifiable dose-response pattern in residing proximity to nuclear plants at the time of diagnosis and cancer risk was not observed.

The relative risk of childhood cancer and 95% CI obtained from Poisson regression after controlling for age, sex, and race are shown in Table 3. Relative to the incidence in children residing outside the 30-mile radius of any nuclear plants, there was no significant increase in incidence for children living nearer nuclear plants for leukemia, lymphomas, central nervous system tumors, sympathetic nervous system tumors, retinoblastoma, renal tumors, malignant bone tumors, or soft tissue sarcomas. Similar to the SIR findings, no identifiable dose-response pattern was observed.

COMMENT

This study evaluated the cancer risk for Illinois children 0 to 14 years old in proximity to nuclear power plants for the periods of 1986-1995 and 1996-2005 and did not find any statistically significant increase in pediatric cancer incidence for children living near nuclear power plants. These results are consistent with other studies of populations living near nuclear installations.^{3,10,11,18,19}

Most of the studies on childhood cancer in the vicinity of various nuclear installations have been conducted in Europe and focused on leukemia, as it may be initiated by bone- and bone-marrow-seeking radioisotopes such as strontium-89 and -90, and barium-140. These fission products are not found in natural background radiation, but are exclusively by-products of nuclear weapons explosions and nuclear reactor operations.⁸ The present study did not find any significant excess rate or dose-response patterns of leukemia for children living near the nuclear plants in Illinois.

Although the United States is home to nearly one-fourth of all nuclear power reactors worldwide – the site of 104 of the world’s 440 (as of date) commercial nuclear power reactors – few studies in the United States have examined the childhood cancer rates near nuclear plants. A recent meta-analysis of standardized incidence and mortality rates of childhood leukemia in proximity to nuclear facilities included 17 studies, only one of which was conducted in the United States.⁹ The United States study examined cancer mortality rates in 107 counties with or near nuclear plants that began operating before 1982, it also examined cancer incidence for 5 counties near 4 nuclear plants in Connecticut and Iowa where incidence data were available.³ The authors noticed a significant excess in childhood leukemia for one facility after startup, but the increase also predated the operation of this facility.

A more recent study analyzed childhood cancer incidence and mortality for the years 1988 to 1997 for 49 counties situated mostly or completely within 30 miles (48 km) of 24 nuclear reactors and 14 nuclear plants in the eastern United States.⁸ The study observed significant excesses for both overall cancer incidence and mortality and for leukemia as compared to the SEER rates. However, further analyses by individual state showed that the total excess incidence derived from comparing the counties near reactors with those in the rest of the state did not reach to significance; the authors also noted that the study did not examine cancer patterns for residents living beyond the 30-mile radius from reactors and did not adjust for the potential confounders such as race. More importantly, combining cancer incidence of the residents living within 30-mile radius from different states and comparing it to the SEER rates might introduce bias because it is well known that cancer rates are affected by multiple factors, including demographics, and varies geographically.

The present study has several strengths. It uses population-based cancer incidence data for the last 20 years in Illinois and is one of the largest incidence studies of childhood cancer and nuclear plants. Although the findings in this study were separately presented for the periods 1986-1995 and 1996-2005 due to concerns for the differences in data completeness of different periods, the analyses for the combined 20-year data yielded the same conclusion (not shown). It is also the first study in the United States that relied on ZIP Code areas rather than county to define the distance to nuclear power plants. With the calculation of great circle distance from ZIP Code centroid to nuclear power plants, we were able to define geographically 4 exposure zones and thus examine the potential dose-response relationship. Furthermore, Poisson regression analysis was used in the present study with age, gender, and race included in the multivariate model. These 3 demographic variables have been shown to influence childhood cancer incidence rates²⁰ and were adjusted for in this report.

Some limitations of the study should be noted. As with all epidemiologic studies on this subject, the present study did not have actual exposure measurement but instead used the distance to nuclear plants as surrogate.²¹ Although the great circle distance from a nuclear plant to ZIP Code centroids represented an improvement to using the county to define exposure area, distance still does not equate to dosimetric information or the radiological history of an installation's environs. In this respect, the study is "ecological."¹⁶ Using distance to associate cancer incidence with the nuclear power plants as the putative source of contamination has some limitations. This approximation might prove to be inadequate, as radioactive particles can travel considerable

distances through contaminated air and water. Topology, wind directions, and water flows can all affect the exposure levels and thus may affect our findings.

Another limitation of the study is the lack of data on potential confounding factors other than age, sex, and race. For example, there may be differences in socioeconomic status in the 4 study zones that may confound the observed associations. Additionally, as in any studies using central registry data, the exact history of residence was not known for cases; it is possible that some cases resided for part of their lives in an exposed area and then moved to an unexposed area and vice versa. This effect, however, could be expected to be nondifferential as populations in the 4 study zones were relatively stable between Census 1990 and Census 2000. To our knowledge, there have been no reports of any appreciable mass migrations to or out of one particular geographic zone. Furthermore, lack of information on length of residence as well as maternal exposure restrained us from calculating person-years and consideration of whether exposure occurred before or after birth.

Empirical small-area analyses have found inconsistencies across models using different areal aggregations, which has been named the modifiable areal unit problem, or MAUP.²² In the present study, as ZIP Code centroids were used in defining exposure zones, some ZIP Codes may be located in more than 1 zone. Moreover, because the distance used to define exposure zone itself was arbitrary, it is possible that the results of this study may be affected by MAUP. Nevertheless, additional analyses with cutoff point (distance to the plants) of 1 mile or 5 miles produced the similar results.

In summary, this study did not find childhood cancer excess among children living near nuclear plants in Illinois and did not observe any dose-response patterns in cancer incidence in proximity to nuclear plants. The interpretation of these findings should be approached with caution because of the nature of the study and the study limitations discussed above.

Fig. 1. Geographic exposure zones by distance from ZIP Code centroid to nuclear power plants, Illinois

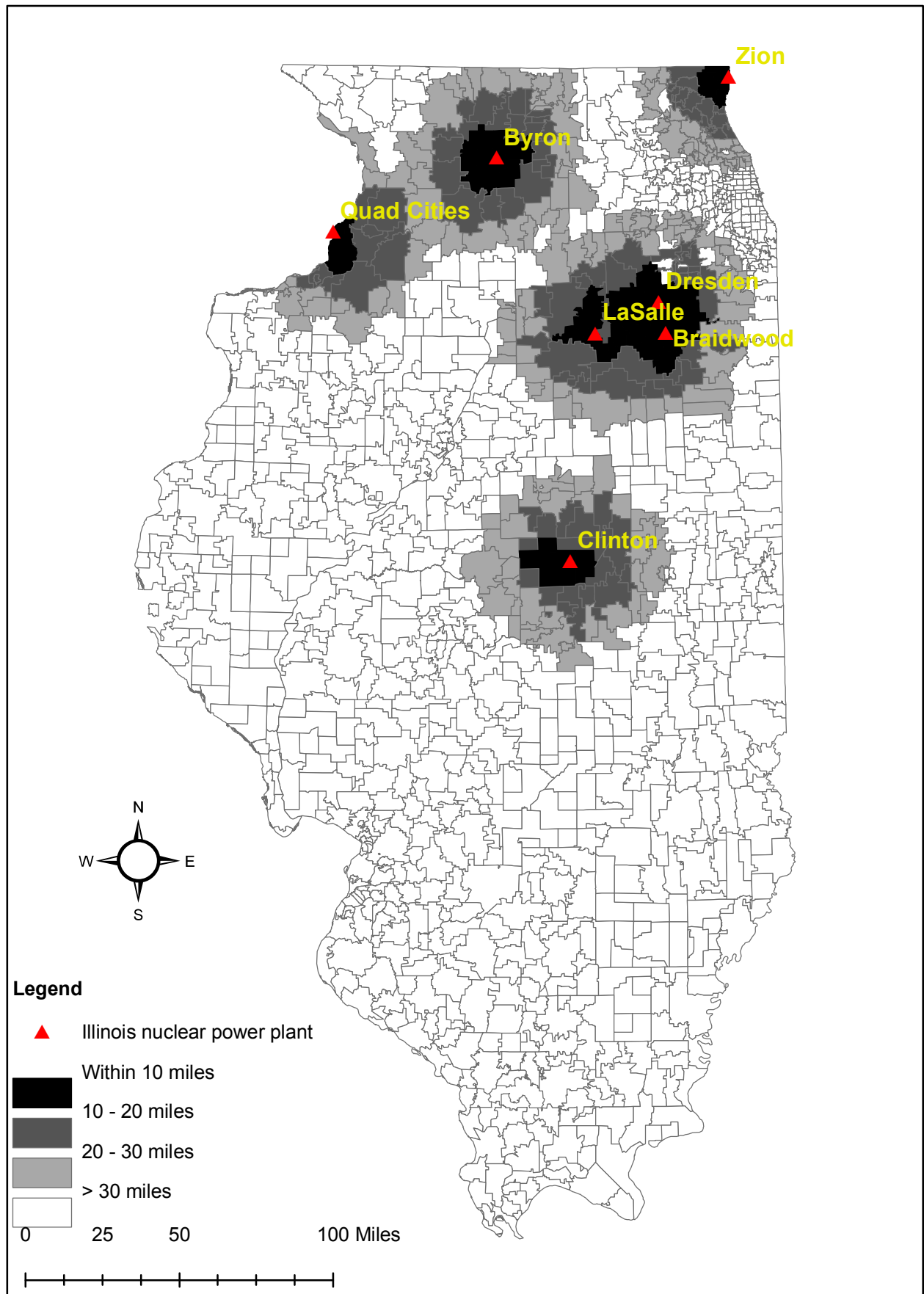


Table 1.—Overall Childhood Cancer Case Counts (Ages 0 to 14) and the Census Populations by Proximity to Nuclear Power Plant, All Races, Both Sexes, Illinois

Proximity (mile)	Overall cases 1986-1995	Census 1990 population	Overall cases 1996-2005	Census 2000 population
≤10	97	67,476	127	80,515
>10 and ≤20	309	211,256	387	254,380
>20 and ≤30	714	466,711	898	556,312
>30	2,382	1,685,287	2,525	1,819,636
Total	3,502	2,430,720	3,937	2,710,843

Table 2.—Standardized Incidence Ratio for Childhood Cancer (Ages 0 to 14) by Cancer Site and Proximity to Nuclear Power Plant, All Races, Both Sexes, Illinois

Cancer site	Proximity (mile)	Study period 1986-1995					Study period 1996-2005				
		Observed	Expected	SIR*	Lower 95% CI	Upper 95% CI	Observed	Expected	SIR*	Lower 95% CI	Upper 95% CI
Leukemia	≤10	24	28	0.85	0.54	1.26	47	38	1.23	0.91	1.64
	>10 and ≤20	95	88	1.08	0.87	1.31	116	119	0.97	0.80	1.17
	>20 and ≤30	211	196	1.08	0.94	1.23	287	258	1.11	0.99	1.25
	>30	739	705	1.05	0.97	1.13	815	851	0.96	0.89	1.03
Lymphomas and reticuloendothelial neoplasms	≤10	15	11	1.38	0.77	2.27	10	13	0.77	0.37	1.42
	>10 and ≤20	37	34	1.08	0.76	1.49	42	41	1.02	0.73	1.38
	>20 and ≤30	85	75	1.13	0.90	1.39	100	91	1.10	0.89	1.34
	>30	274	273	1.00	0.89	1.13	286	295	0.97	0.86	1.09
CNS and miscellaneous intracranial and intraspinal neoplasms	≤10	23	20	1.15	0.73	1.73	24	23	1.02	0.65	1.52
	>10 and ≤20	66	62	1.06	0.82	1.35	88	74	1.19	0.95	1.47
	>20 and ≤30	160	138	1.16	0.99	1.36	175	161	1.09	0.93	1.26
	>30	500	497	1.01	0.92	1.10	496	529	0.94	0.86	1.02
Sympathetic nervous system	≤10	12	7	1.62	0.83	2.82	11	9	1.17	0.59	2.10
	>10 and ≤20	17	23	0.74	0.43	1.19	30	29	1.04	0.70	1.48
	>20 and ≤30	56	51	1.09	0.82	1.42	73	61	1.19	0.93	1.49
	>30	197	184	1.07	0.93	1.23	195	206	0.95	0.82	1.09
Retinoblastoma	≤10	1	3	0.34	0.00	1.91	5	3	1.77	0.57	4.14
	>10 and ≤20	9	9	1.00	0.46	1.90	10	9	1.15	0.55	2.11
	>20 and ≤30	17	20	0.84	0.49	1.35	21	18	1.15	0.71	1.75
	>30	84	72	1.16	0.93	1.44	57	62	0.92	0.70	1.19
Renal tumors	≤10	3	6	0.50	0.10	1.45	6	7	0.90	0.33	1.95
	>10 and ≤20	21	19	1.12	0.69	1.71	22	21	1.06	0.66	1.61
	>20 and ≤30	45	42	1.08	0.78	1.44	48	44	1.09	0.80	1.44
	>30	160	150	1.07	0.91	1.24	145	148	0.98	0.83	1.15
Hepatic tumors	≤10	0	1	n/a	n/a	n/a	2	2	1.14	0.13	4.13
	>10 and ≤20	1	4	0.28	0.00	1.55	7	5	1.29	0.52	2.65
	>20 and ≤30	14	8	1.75	0.95	2.93	13	12	1.12	0.60	1.92
	>30	29	29	1.01	0.68	1.45	36	39	0.93	0.65	1.29

(Continued on next page)

Table 2. –Standardized Incidence Ratio for Childhood Cancer (Ages 0 to 14) by Cancer Site and Proximity to Nuclear Power Plant, All Races, Both Sexes, Illinois

Cancer site	Proximity (mile)	Study period 1986-1995					Study period 1996-2005				
		Observed	Expected	SIR*	Lower 95% CI	Upper 95% CI	Observed	Expected	SIR*	Lower 95% CI	Upper 95% CI
Malignant bone tumors	≤10	4	3	1.19	0.32	3.04	4	5	0.78	0.21	2.00
	>10 and ≤20	16	11	1.51	0.86	2.44	19	16	1.15	0.69	1.80
	>20 and ≤30	26	23	1.11	0.73	1.63	41	37	1.12	0.80	1.51
	>30	81	85	0.95	0.76	1.19	111	118	0.94	0.77	1.13
Soft tissue sarcomas	≤10	7	6	1.13	0.45	2.32	10	8	1.23	0.59	2.27
	>10 and ≤20	19	19	0.98	0.59	1.52	29	26	1.13	0.76	1.62
	>20 and ≤30	51	43	1.18	0.88	1.56	59	56	1.05	0.80	1.35
	>30	158	156	1.02	0.86	1.19	175	184	0.95	0.82	1.11
Germ-cell, trophoblastic and other gonadal tumors	≤10	4	3	1.16	0.31	2.98	1	4	0.25	0.00	1.37
	>10 and ≤20	13	11	1.21	0.64	2.07	11	13	0.85	0.43	1.53
	>20 and ≤30	23	24	0.97	0.61	1.45	34	28	1.21	0.84	1.70
	>30	90	86	1.05	0.84	1.29	91	92	0.99	0.80	1.22
Carcinomas and other malignant epithelial neoplasms	≤10	4	2	1.63	0.44	4.18	7	5	1.44	0.58	2.96
	>10 and ≤20	13	8	1.68	0.89	2.88	10	16	0.64	0.31	1.17
	>20 and ≤30	17	17	1.00	0.58	1.60	44	35	1.26	0.92	1.69
	>30	59	62	0.95	0.73	1.23	106	112	0.94	0.77	1.14
Other unspecified malignant tumors	≤10	0	0	n/a	n/a	n/a	0	0	n/a	n/a	n/a
	>10 and ≤20	2	1	1.43	0.16	5.16	1	1	0.97	0.01	5.40
	>20 and ≤30	6	3	1.93	0.70	4.20	2	2	0.88	0.10	3.18
	>30	9	11	0.81	0.37	1.53	8	7	1.08	0.46	2.12
Other and unspecified malignant neoplasms	≤10	0	0	n/a	n/a	n/a	0	0	n/a	n/a	n/a
	>10 and ≤20	0	0	n/a	n/a	n/a	2	1	3.03	0.34	10.94
	>20 and ≤30	3	1	3.26	0.66	9.53	1	1	0.71	0.01	3.97
	>30	2	3	0.60	0.07	2.17	4	5	0.85	0.23	2.17

*Standardized incidence ratio.

Table 3.—Relative Risk of Childhood Cancer (Ages 0 to 14) by Proximity to Nuclear Power Plants, Illinois

Cancer site	Proximity (mile)	Study period 1986-1995			Study period 1996-2005		
		RR*	Lower 95% CI	Upper 95% CI	RR*	Lower 95% CI	Upper 95% CI
Leukemia	≤10	0.75	0.50	1.12	1.24	0.92	1.66
	>10 and ≤20	0.90	0.73	1.13	0.87	0.71	1.06
	>20 and ≤30	0.90	0.77	1.05	1.01	0.88	1.16
	>30	1.00			1.00		
Lymphomas and reticuloendothelial neoplasms	≤10	1.32	0.79	2.23	0.80	0.43	1.51
	>10 and ≤20	1.01	0.71	1.43	0.98	0.71	1.36
	>20 and ≤30	1.06	0.83	1.36	1.08	0.85	1.36
	>30	1.00			1.00		
CNS and miscellaneous intracranial and intraspinal neoplasms	≤10	1.09	0.72	1.65	1.07	0.71	1.62
	>10 and ≤20	0.95	0.74	1.23	1.14	0.91	1.43
	>20 and ≤30	1.05	0.88	1.26	1.06	0.89	1.26
	>30	1.00			1.00		
Sympathetic nervous system	≤10	1.40	0.78	2.51	1.20	0.66	2.21
	>10 and ≤20	0.60	0.37	0.99	0.94	0.64	1.38
	>20 and ≤30	0.89	0.66	1.21	1.10	0.84	1.44
	>30	1.00			1.00		
Retinoblastoma	≤10	0.31	0.04	2.23	2.05	0.82	5.13
	>10 and ≤20	0.92	0.46	1.85	1.32	0.67	2.60
	>20 and ≤30	0.79	0.46	1.34	1.33	0.79	2.21
	>30	1.00			1.00		
Renal tumors	≤10	0.48	0.15	1.51	0.95	0.42	2.16
	>10 and ≤20	1.08	0.68	1.72	1.07	0.68	1.69
	>20 and ≤30	1.06	0.75	1.49	1.11	0.80	1.55
	>30	1.00			1.00		
Malignant bone tumors	≤10	1.20	0.44	3.28	0.81	0.30	2.21
	>10 and ≤20	1.47	0.85	2.52	1.09	0.67	1.79
	>20 and ≤30	1.09	0.70	1.71	1.08	0.75	1.55
	>30	1.00			1.00		
Soft tissue sarcomas	≤10	1.07	0.50	2.29	1.30	0.69	2.46
	>10 and ≤20	0.90	0.56	1.45	1.12	0.75	1.66
	>20 and ≤30	1.10	0.80	1.52	1.05	0.78	1.42
	>30	1.00			1.00		

*Relative Risk

References

1. Black RJ, Sharp L, Harkness EF, McKinney PA. Leukaemia and non-Hodgkin's lymphoma: incidence in children and young adults resident in the Dounreay area of Caithness, Scotland in 1968-91. *J Epidemiol Community Health*. 1994;48(3):232-236.
2. Draper GJ, Stiller CA, Cartwright RA, Craft AW, Vincent TJ. Cancer in Cumbria and in the vicinity of the Sellafield nuclear installation, 1963-90. *BMJ*. 1993;306(6870):89-94.
3. Jablon S, Hrubec Z, Boice JD, Jr. Cancer in populations living near nuclear facilities. A survey of mortality nationwide and incidence in two states. *JAMA*. 1991;265(11):1403-1408.
4. Michaelis J, Keller B, Haaf G, Kaatsch P. Incidence of childhood malignancies in the vicinity of west German nuclear power plants. *Cancer Causes Control*. 1992;3(3):255-263.
5. Sharp L, McKinney PA, Black RJ. Incidence of childhood brain and other non-haematopoietic neoplasms near nuclear sites in Scotland, 1975-94. *Occup Environ Med*. 1999;56(5):308-314.
6. Silva-Mato A, Viana D, Fernandez-SanMartin MI, Cobos J, Viana M. Cancer risk around the nuclear power plants of Trillo and Zorita (Spain). *Occup Environ Med*. 2003;60(7):521-527.
7. Viel JF, Richardson S, Danel P, Boutard P, Malet M, Barrelier P et al. Childhood leukemia incidence in the vicinity of La Hague nuclear-waste reprocessing facility (France). *Cancer Causes Control*. 1993;4(4):341-343.
8. Mangano JJ, Sherman J, Chang C, Dave A, Feinberg E, Frimer M. Elevated childhood cancer incidence proximate to U.S. nuclear power plants. *Arch Environ Health*. 2003;58(2):74-82.
9. Baker PJ, Hoel DG. Meta-analysis of standardized incidence and mortality rates of childhood leukaemia in proximity to nuclear facilities. *Eur J Cancer Care*. (Engl) 2007;16(4):355-363.
10. Sharp L, Black RJ, Harkness EF, McKinney PA. Incidence of childhood leukaemia and non-Hodgkin's lymphoma in the vicinity of nuclear sites in Scotland, 1968-93. *Occup Environ Med*. 1996;53(12):823-831.
11. White-Koning ML, Hemon D, Laurier D, Tirmarche M, Jouglu E, Goubin A et al. Incidence of childhood leukaemia in the vicinity of nuclear sites in France, 1990-1998. *Br J Cancer*. 2004;91(5):916-922.
12. Wakeford R, Berry RJ. Nuclear energy facilities and cancers. *Ann Acad Med*. Singapore 1996;25(3):468-476.

13. Mangano J, Sherman JD. Childhood leukaemia near nuclear installations. *Eur J Cancer Care*. (Engl) 2008;17(4):416-418.
14. Goldsmith JR. Nuclear installations and childhood cancer in the UK: mortality and incidence for 0-9-year-old children, 1971-1980. *Sci Total Environ*. 1992;127(1-2):13-35.
15. Hattchouel JM, Laplanche A, Hill C. Leukaemia mortality around French nuclear sites. *Br J Cancer*. 1995;71(3):651-653.
16. Lopez-Abente G, Aragonés N, Pollán M, Ruiz M, Gandarillas A. Leukemia, lymphomas, and myeloma mortality in the vicinity of nuclear power plants and nuclear fuel facilities in Spain. *Cancer Epidemiol Biomarkers Prev*. 1999;8(10):925-934.
17. Steliarova-Foucher E, Stiller C, Lacour B, Kaatsch P. International Classification of Childhood Cancer, third edition. *Cancer*. 2005;103(7):1457-1467.
18. Boice JD, Jr., Bigbee WL, Mumma MT, Blot WJ. Cancer incidence in municipalities near two former nuclear materials processing facilities in Pennsylvania. *Health Phys*. 2003;85(6):678-690.
19. Michaelis J. Recent epidemiological studies on ionizing radiation and childhood cancer in Germany. *Int J Radiat Biol* 1998;73(4):377-381.
20. Ries LAG., Smith MAGJG., Linet M., Tamra T., Young JLBGR., eds. *Cancer incidence and survival among children and adolescents: United States SEER program 1975-1995*. Bethesda, MD: National Cancer Institute, SEER Program, 1999.
21. Lawson AB. On the analysis of mortality events associated with a prespecified fixed point. *J R Stat Soc Ser A Stat Soc*. 1993;156(3):363-377.
22. Cockings S, Martin D. Zone design for environment and health studies using pre-aggregated data. *Soc Sci Med*. 2005;60(12):2729-2742.