Pediatric Cancer Incidence and Mortality in the Vicinity of Nuclear Power Plants in Illinois

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ABSTRACT

BACKGROUND: There has always been public concern over the cancer risk for people living near nuclear facilities. With a number of nuclear power plants operated throughout the state of Illinois, the current study was conducted to address this concern.

OBJECTIVE: Examined the pediatric cancer risk in relation to the proximity of nuclear power plants in Illinois.

METHODS: Evaluations were conducted at both the county and ZIP code levels. Age-adjusted cancer incidence and mortality rates for children aged from 0 to 14 for years 1990 to 2002 were calculated for nuclear facility county group (NFCG) and nuclear facility ZIP code group (NFZG), respectively, and then compared with those for the matched non-nuclear facility county group (NNFCG) or non-nuclear facility ZIP code group (NNFZG). The statistical significance of the rate difference was determined from rate ratio and associated 95 percentage confidence interval. Rates based on state and national levels served as additional comparisons. A Poisson regression analysis was performed to evaluate the effect of proximity to nuclear power plants on cancer incidence while adjusting for race, sex and age.

RESULTS AND CONCLUSIONS: Pediatric cancer incidence and mortality rates for NFCG or NFZG were not significantly different from those for their comparison groups. In addition, there was no evidence of increased trend in cancer incidence rate after startup of nuclear power plants. The Poisson regression model showed that proximity to nuclear power plants was not a significant indicator of variation of cancer incidence. This study confirmed research findings reported previously in Illinois. However, continued monitoring of cancer risk in the concerned area is warranted.

INTRODUCTION

There has always been public concern over the cancer risk for people living near nuclear facilities. During the last two decades, a large number of studies have been conducted to evaluate the risk across different countries.[1-13] Since children seem more susceptible to radiation exposure and also cancers developed on children have relatively short latency period, many of these studies have focused on children population.[2,4-7,10,13] The cancer sites examined most frequently include leukemia, lymphoma, thyroid, brain and myeloma.[4-5,7-8,10] Some studies have reported elevated risk for certain type of cancers.[3-4,10,12] However, many others failed to confirm or did not find evidence of increased risk.[1,5-6,11,13]

With the fact that Illinois ranks first among all states in the United States for the number of commercial nuclear facilities as well as the total nuclear capacity,[14] in 2000, the Division of Epidemiologic Studies, Illinois Department of Public Health conducted an investigation to evaluate the pediatric cancer risk and proximity to nuclear facilities.[15] The study found no significant cancer incidence rate differences for Illinois children residing in counties with nuclear facilities as compared with those in comparable counties without such facilities. Several years have passed since the previous study. With more cancer data becoming available in the cancer registry, the research findings reported previously were reappraised in the current study. In addition, besides the county level evaluation, an analysis based on a finer geographical area - ZIP code level - was performed. Mortality information in the county level was added as well in this study.

METHODS

Nuclear power plants in Illinois

There have been seven nuclear power plants in Illinois with a total of 12 nuclear reactors. Six plants are still in operation and one was closed in 1998. These seven nuclear power plants geographically reside in the following seven different counties: Braidwood in Will County (reactor 1 licensed in July 1987; reactor 2 in May 1988), Byron in Ogle County (reactor 1 licensed in February 1985; reactor 2 in January 1987), Clinton in DeWitt County (licensed in April 1987), Dresden in Grundy County (reactor 2 licensed in February 1991; reactor 3 in January1971), LaSalle in LaSalle County (reactor 1 licensed in April 1982; reactor 2 in February 1983), Quad Cities in Rock Island County (reactor 1 and 2 licensed in December 1972) and Zion in Lake County (licensed in October 1973 and closed in January 1998).

Study designs

The current study was designed for analysis in two different levels: county level and ZIP code level. For county level analysis, the same approach as used in the previous study[14] was applied. The seven counties with nuclear facilities were combined to form the nuclear facility county group (NFCG). Each of these counties was matched to a comparison county. The criteria for matching included population density, childhood age distribution and similar racial composition. Once these criteria were met, an effort was made to select a comparison county that was geographically distant from any counties with nuclear facilities. The seven matched counties selected, including Adams, Champaign, DuPage, Kane, Macoupin, McDonough and Richland, were combined to form the non-nuclear facility county group (NNFCG) (Figure 1).

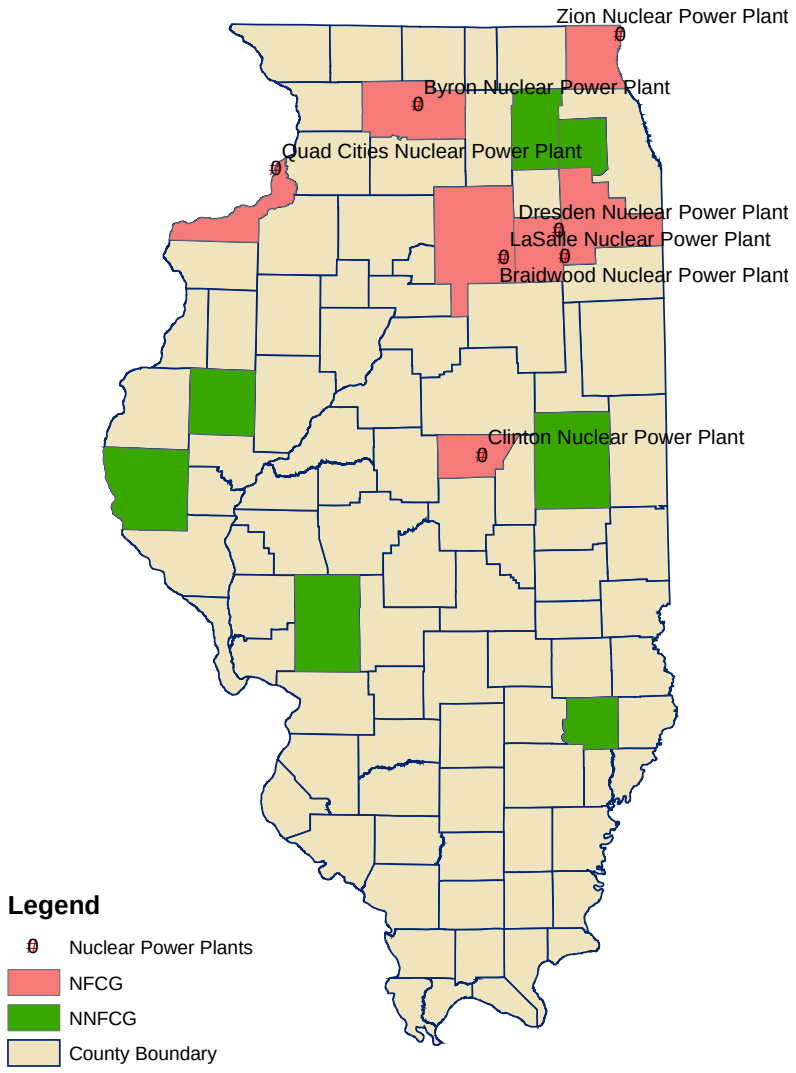

Figure 1. Map of Illinois showing nuclear power plants, nuclear facility county group (NFCG) and non-nuclear facility county group (NNFCG)

For ZIP code level analysis, the ZIP codes containing or surrounding each nuclear power facility were identified (Table1), and all these ZIP codes were combined to form a nuclear facility ZIP code group (NFZG). The comparison group, non-nuclear facility ZIP code group (NNFZG), was formed by the rest of ZIP codes in Illinois with exclusion of the ZIP codes falling into Cook County (Figure 2), since population characteristics in Cook County were far more different from those in the rest of the state.

Table 1. ZIP codes included in the nuclear facility ZIP code group (NFZG)

Nuclear Power Plants	Surrounding ZIP Codes
Clinton Nuclear Power Plant	61723, 61727, 61735, 61749, 61756, 61777, 61778, 61842, 61882, 62501, 62512
Quad Cities Nuclear Power Plant	61230, 61242, 61257, 61275
Byron Nuclear Power Plant	61010, 61015, 61047, 61054, 61061, 61084, 61088, 61102
Zion Nuclear Power Plant	60002, 60083, 60087, 60096, 60099
LaSalle Nuclear Power Plant Braidwood Nuclear Power Plant Dresden Nuclear Power Plant	60407, 60408, 60410, 60416, 60424, 60437, 60444, 60447, 60450, 60470, 60479, 60481, 60935, 61325, 61360

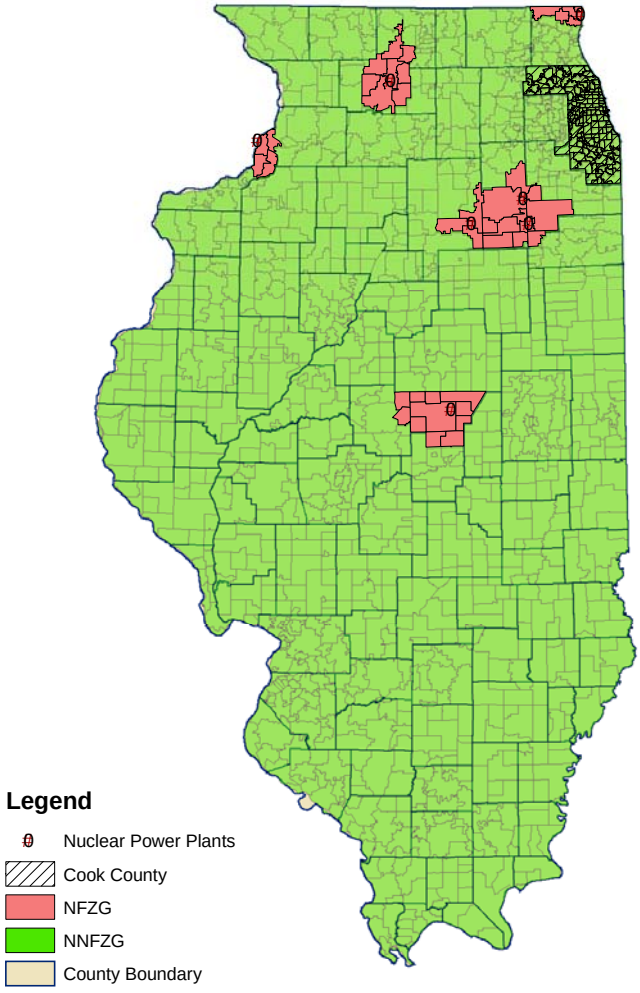

Figure 2. Map of Illinois showing nuclear power plants, nuclear facility ZIP code group (NFZG) and non-nuclear facility ZIP code group (NNFZG)

Cancer incidence and mortality

Cancer incidence data were from the Illinois State Cancer Registry (ISCR), the only source of population-based cancer incidence data for the state. In the current evaluation, only cancer cases diagnosed for Illinois children (aged from 0 to 14 years) were considered. Pediatric cancer diagnostic groups were defined according to the scheme of SEER modified International Classification of Childhood Cancer (ICCC).[16] For county level evaluation, all invasive cancer cases diagnosed on Illinois children from 1990 through 2002 in seven nuclear facility counties and seven matched non-nuclear facility counties were selected for analysis. For ZIP code level evaluation, cancer cases diagnosed during the same time period in two different ZIP code groups were selected for analysis.

The National Cancer Institute's (NCI) Surveillance, Epidemiology and End Results (SEER) program was the source of information for cancer mortality.[17] The cancer deaths were recoded as SEER Cause of Death groups based on the International Classification of Diseases codes (ICD-9 code[18] used for death before 1998 and ICD-10 code[19] used for death on and after 1999). In this study, all cancer related deaths and five specific cancer deaths (brain and other nervous system, thyroid, leukemia, lymphoma and myeloma) for Illinois children from 1990 to 2002 were evaluated in county group level. Since there was no ZIP code information available in the mortality database, no ZIP code level analysis was performed for mortality data.

Population estimates

Estimates of county populations, representing a modification of the county population estimates produced by the U.S. Census Bureau's Population Estimates Program, were obtained from the NCI's SEER program. The methodology for these estimates is available at the following Web site, www.seer.cancer.gov/popdata/methods.pdf. Population estimates for ZIP code were derived by interpolating the population counts for each ZIP code from the 1990 and 2000 U.S. Census, the most reliable sources for small area population. An exponential function was used for the interpolation when population counts for both 1990 and 2000 censuses were nonzero. However, if population count for either 1990 or 2000 was zero, a linear function was used instead, since under this situation, it was not possible to fit an exponential function.

Statistical analysis

For the county level analysis, annual age-adjusted cancer incidence and mortality rates were calculated for the nuclear facility county group (NFCG) and the non-nuclear facility county group (NNFCG) respectively, using Seer*Stat software (version 6.1). Rate ratios between two county groups were also calculated, and statistical significance of rate differences were determined based on the 95 percentage confidence intervals for rate ratio. To evaluate the trend of cancer incidence over time, annual percentage change (APC) of incidence rate for two county groups from 1986 to 2002 were examined and compared. APC was calculated by fitting a least square regression line to the natural logarithm of the rates, using the calendar year as a regressor variable.

Similarly, for the ZIP code level analysis, annual age-adjusted cancer incidence rates were calculated for the nuclear facility ZIP code group (NFZG) and the non-nuclear

facility ZIP code group (NNFZG), respectively, and rate ratio and associated 95 percentage confidence interval were used to determine the statistical significance of rate difference.

For both levels of analysis, cancer incidence rates for the state of Illinois and SEER 9 cancer registries[20] (representing U.S.) were also calculated as additional comparisons to that for NFCG and NFZG. However, cancer mortality rates for Illinois and U.S. were calculated and compared with that for NFCG only.

Finally, to evaluate the effect of proximity to nuclear power plants on cancer incidence while controlling for other factors, Poisson regression analysis was performed for county level and ZIP code level data, respectively. In the regression model, the response (dependent) variable was the number of cancer cases in each of 14 counties (or in each of 1053 ZIP codes), and the independent variables was proximity status to nuclear power plants (yes or no). The population count in each counties (or ZIP code) was used as offset variable, and population distributions by race, sex, or age were used as covariates. The statistical significance was determined based on P values ≤ 0.05.

RESULTS

Table 2 shows cancer incidence by major pediatric cancer sites for the nuclear facility county group (NFCG) and three comparison groups (NNFCG, Illinois state and SEER 9 registries). No significant rate differences were found between NFCG and any of the three comparison groups. Cancer mortality for all cancer sites combined and five specific cancers are given in Table 3. No significant rate differences were detected either.

Table 2. Pediatric (aged 0-14) cancer incidence by cancer site and comparison group (county group level), all races, both sexes, 1990-2002

Cancer	Comparison Group	Incidence Count	Incidence Rate[1]	Rate Ratio	95% Confidence Interval for Rate Ratio
All Diagnostic Groups	NFCG[2]	651	148.7	~	~
	NNFCG[3]	676	145.0	1.03	0.92-1.14
	Illinois	4,795	138.4	1.07	0.99-1.17
	SEER 9[4]	10,533	145.1	1.02	0.95-1.11
Leukemia	NFCG	191	43.2	~	~
	NNFCG	226	48.0	0.90	0.74-1.10
	Illinois	1,511	43.4	0.99	0.85-1.16
	SEER 9	3,194	43.8	0.99	0.85-1.14
Lymphoma	NFCG	60	13.9	~	~
	NNFCG	74	16.4	0.85	0.59-1.21
	Illinois	514	15.2	0.92	0.69-1.20
	SEER 9	1,012	14.3	0.98	0.76-1.27
Central Nervous System	NFCG	134	30.8	~	~
	NNFCG	141	30.5	1.01	0.79-1.29
	Illinois	1,002	29.1	1.06	0.88-1.27
	SEER 9	2,361	32.7	0.94	0.80-1.12
Sympathetic Nervous System	NFCG	57	12.8	~	~
	NNFCG	50	10.4	1.23	0.83-1.84
	Illinois	383	10.7	1.19	0.89-1.58
	SEER 9	836	11.2	1.14	0.86-1.52
Retinoblastoma	NFCG	22	4.9	~	~
	NNFCG	14	2.9	1.71	0.83-3.63
	Illinois	134	3.7	1.32	0.80-2.09
	SEER 9	320	4.3	1.15	0.73-1.81
Renal Tumors	NFCG	40	8.9	~	~
	NNFCG	44	9.1	0.98	0.62-1.54
	Illinois	289	8.1	1.10	0.77-1.53
	SEER 9	646	8.7	1.02	0.74-1.41
Hepatic Tumors	NFCG	11	2.5	~	~
	NNFCG	12	2.5	1.00	0.40-2.49
	Illinois	64	1.8	1.37	0.65-2.63
	SEER 9	164	2.2	1.12	0.59-2.12
Malignant Bone Tumors	NFCG	29	6.8	~	~
	NNFCG	32	7.2	0.95	0.55-1.62
	Illinois	213	6.4	1.07	0.70-1.59
	SEER 9	452	6.4	1.07	0.73-1.57
Soft Tissue Sarcomas	NFCG	50	11.5	~	~
	NNFCG	47	10.1	1.13	0.74-1.73
	Illinois	340	9.9	1.16	0.85-1.57
	SEER 9	742	10.3	1.11	0.82-1.50
Germ Cell, Trophoblastic and Other Gonadal	NFCG	24	5.6	~	~
	NNFCG	16	3.5	1.60	0.81-3.24
	Illinois	166	4.8	1.16	0.72-1.78
	SEER 9	371	5.1	1.09	0.71-1.67
Carcinomas and Other Malignant Epithelial	NFCG	27	6.4	~	~
	NNFCG	17	3.8	1.66	0.87-3.26
	Illinois	154	4.6	1.39	0.88-2.10
	SEER 9	404	5.7	1.11	0.74-1.67

Table 2. Cont.

Cancer	Comparison Group	Incidence Count	Incidence Rate[1]	Rate Ratio	95% Confidence Interval for Rate Ratio
Other and Unspecified Malignant Neoplasms	NFCG[2]	6	1.4	~	~
	NNFCG[3]	3	0.7	2.08	0.44-12.92
	Illinois S	25	0.7	1.93	0.65-4.85
	SEER 9[4]	31	0.4	3.17	0.81-12.38

1. Rates are per 1,000,000 and are age-adjusted to the 2000 U.S. standard population.
2. NFCG: nuclear facility county group, including DeWitt, Grundy, Lake, LaSalle, Ogle, Rock Island and Will.
3. NNFCG: non-nuclear facility county group, including Adams, Champaign, DuPage, Kane, Macoupin, McDonough and Richland.
4. SEER 9 registries are Connecticut, Iowa, New Mexico, Utah, Hawaii, Detroit, San Francisco-Oakland, Atlanta, Seattle-Puget Sound.

~ Not applicable.

Table 3. Pediatric (aged 0-14) cancer mortality by cancer site and comparison group, all races, both sexes, 1990-2002

Cancer	Comparison Group	Death Count	Mortality Rate[1]	Rate Ratio	95% Confidence Interval for Rate Ratio
All Malignant Cancers	NFCG[2]	109	25.0	~	~
	NNFCG[3]	98	21.4	1.17	0.88-1.55
	Illinois	894	26.0	0.96	0.78-1.17
	United States	20,619	27.2	0.92	0.75-1.11
Brain and Other Nervous System	NFCG	26	6.0	~	~
	NNFCG	28	6.1	0.98	0.55-1.74
	Illinois	240	7.0	0.86	0.55-1.29
	United States	5,781	7.6	0.79	0.51-1.16
Thyroid	NFCG	0	0	~	~
	NNFCG	0	0	~	~
	Illinois	0	0	~	~
	United States	6	0.008	~	~
Lymphoma	NFCG	4	0.9	~	~
	NNFCG	8	1.8	0.52	0.11-1.94
	Illinois	46	1.3	0.68	0.18-1.87
	United States	1,009	1.3	0.68	0.18-1.76
Myeloma	NFCG	0	0	~	~
	NNFCG	0	0	~	~
	Illinois	1	0.03	~	~
	United States	8	0.01	~	~
Leukemia	NFCG	41	9.4	~	~
	NNFCG	40	8.7	1.07	0.67-1.70
	Illinois	300	8.8	1.07	0.75-1.49
	United States	6,950	9.2	1.02	0.73-1.39

1. Rates are per 1,000,000 and are age-adjusted to the 2000 U.S. standard population.
2. NFCG: nuclear facility county group, including DeWitt, Grundy, Lake, LaSalle, Ogle, Rock Island and Will.
3. NNFCG: non-nuclear facility county group, including Adams, Champaign, DuPage, Kane, Macoupin, McDonough and Richland.

~ Not applicable or can't be calculated.

Table 4 shows trend analysis result for cancer incidence rate for all cancer diagnostic group and three specific cancers (leukemia, lymphoma and central nervous system) that had sufficient number of cases for the calculation of annual percentage change (APC) of rate. Since the numbers of cases for the other cancer groups were too small (i.e., having 0 case for an individual year) in either NFCG or NNFCG, APC was not calculated. For NFCG, NNFCG and SEER 9 registries, no significant rate changes were detected for the cancer groups and time period considered. However, leukemia incidence rate at the state level seemed significantly increasing from 1986 to 2002.

Table 4. Annual percentage change of pediatric (aged 0-14) cancer incidence rate by caner site and comparison group, all races, both sexes, 1986-2002

	NFCG[1]		NNFCG[2]		Illinois		SEER 9[3]	
	APC[4]	P Value	APC	P Value	APC	P Value	APC	P Value
All Diagnostic Groups	0.82	0.37	0.36	0.72	0.66	0.07	0.38	0.08
Leukemia	1.18	0.47	0.56	0.71	1.36*	0.05	0.33	0.33
Lymphoma	-1.82	0.44	0.61	0.74	-0.42	0.6	-0.21	0.70
Central Nervous System	-0.37	0.83	-1.36	0.41	-0.06	0.92	0.24	0.57

1. NFCG: nuclear facility county group, including DeWitt, Grundy, Lake, LaSalle, Ogle, Rock Island and Will.
2. NNFCG: non-nuclear facility county group, including Adams, Champaign, DuPage, Kane, Macoupin, McDonough and Richland.
3. SEER 9 registries are Connecticut, Iowa, New Mexico, Utah, Hawaii, Detroit, San Francisco-Oakland, Atlanta, Seattle-Puget Sound.
4. APC: annual percentage change for rate.

* APC is significantly different from 0.

Table 5 shows the cancer incidence rates for the nuclear facility ZIP code group (NFZG), non-nuclear facility ZIP code group (NNFZG), Illinois state and SEER 9 registries. Only all cancer diagnostic group and three specific cancers of leukemia, lymphoma and central nervous system that had sufficient numbers of cases for

meaningful rate calculation were evaluated. Comparing the rates in NFZG with those in the three other comparison groups, no significant differences were found.

Table 5. Pediatric (aged 0-14) cancer incidence by cancer site and comparison group (ZIP code group level), all races, both sexes, 1990-2002

Cancer	Comparison Group	Incidence Count	Incidence Rate	Rate Ratio[1]	95% Confidence Interval for Rate Ratio
All Diagnostic Groups	NFZG[2]	87	128.7	~	~
	NNFZG[3]	2,313	136.0	0.95	0.77-1.17
	Illinois	4,795	138.4	0.93	0.76-1.14
	SEER 9[4]	10,533	145.1	0.89	0.73-1.08
Leukemia	NFZG	33	48.9	~	~
	NNFZG	704	41.3	1.18	0.81-1.73
	Illinois	1,511	43.4	1.13	0.78-1.62
	SEER 9	3,194	43.8	1.12	0.78-1.61
Lymphoma	NFZG	14	20.7	~	~
	NNFZG	226	13.3	1.55	0.80-2.98
	Illinois	514	15.2	1.36	0.74-2.52
	SEER 9	1,012	14.3	1.45	0.77-2.72
Central Nervous System	NFZG	21	31.0	~	~
	NNFZG	506	29.7	1.04	0.67-1.63
	Illinois	1,002	29.1	1.06	0.68-1.66
	SEER 9	2,361	32.7	0.95	0.62-1.44

1. Rates are per 1,000,000 and are age-adjusted to the 2000 U.S. standard population.
2. NFZG: nuclear facility ZIP code group, including 43 ZIP codes.
3. NNFZG: non-nuclear facility ZIP code group, including 1010 ZIP codes.
4. SEER 9 registries are Connecticut, Iowa, New Mexico, Utah, Hawaii, Detroit, San Francisco-Oakland, Atlanta, Seattle-Puget Sound.

~ Not applicable.

Table 6 shows the effect of proximity to nuclear power plants on the cancer incidence based on Poisson regression analysis after adjusting for race, sex and age. For both county and ZIP code level data, associated P values were greater than 0.05, suggesting that proximity to nuclear power plants was not a significant indicator of risk of cancer.

Table 6. Effect of proximity to nuclear power plants on the pediatric cancer incidence based on Poisson regression model after adjusting for race, sex and age

Data Level	Parameter Estimate	Chi-Square Value	P Value
County Level Data	0.128	2.57	0.11
ZIP Code Level Data	-0.046	0.18	0.67

DISCUSSION

This study has evaluated the cancer risk for Illinois' children who lived near the nuclear power plants based on cancer incidence and mortality data from 1990 to 2002. The evaluations were conducted in both county and ZIP code levels. The study indicated pediatric cancer incidence and mortality rates for the concerned target group (nuclear facility county group or nuclear facility ZIP code group) were not significantly different from those for their comparison groups (non-nuclear facility county group/non-nuclear facility ZIP code group, Illinois and SEER 9 registries). In addition, there were no evidence of increased cancer incidence rate after startup of nuclear power plants. The Poisson regression model also showed that proximity to nuclear power plants was not a significant indicator of variation of cancer incidence. The current study confirmed the previous research findings in Illinois.[15]

The results from this study are also consistent with the findings from many of other studies conducted elsewhere, often in different counties and under diverse settings.[1,5-6,11,13] Despite this, people's doubt about possible cancer risk from living near nuclear power facilities will persist, and continued monitoring of cancer trend for the concerned area is warranted.

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