Paper

CANCER INCIDENCE IN MUNICIPALITIES NEAR TWO FORMER NUCLEAR MATERIALS PROCESSING FACILITIES IN PENNSYLVANIA—AN UPDATE

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Abstract—**Previous studies of cancer incidence among persons living in municipalities within one mile of two nuclear materials processing and fabrication plants in Pennsylvania were extended for the years 1998–2004. It had been shown that mailing addresses for residents of rural areas often did not reflect the actual municipality of residence and, if not corrected, would bias study results. The previous studies had corrected for this bias. Accordingly for the extended study, we obtained mailing addresses from the Pennsylvania Department of Health (PDH) for 866 persons with cancer who presumably lived in one of eight minor civil divisions (MCDs) near or encompassing the former nuclear facilities, designated as Area 1 in previous studies conducted by the PDH. Street addresses were geocoded and local postmasters were asked to place rural delivery addresses, post office boxes and street addresses that could not be geocoded into the correct MCD of actual residence. Over 15% of the mailing addresses were found not to be within the boundaries of the Area 1 municipalities. After the mailing addresses of individuals with cancer were placed in their proper MCD of residence, the number of persons diagnosed with cancer (n = 708) and confirmed to have lived in Area 1 was as expected (728.4) based on cancer incidence rates in the general population of Pennsylvania (SIR 0.97; 95% CI 0.90–1.05). To further evaluate the patterns of cancer rates near these nuclear facilities and the influence of improved reporting and geocoding of addresses over time, analyses were conducted of publicly available cancer incidence data from 1990 through 2004. Based on mailing addresses, a steady decrease in the number of cancers reported in the Area 1 proximal MCDs was seen, in contrast to a steady rise in the number of cancers reported in seven adjacent but more distant MCDs from the nuclear facilities, designated as Area 2. These patterns were attributed to improvements over time in the geocoding of residential mailing addresses coupled with the gradual elimination and replacement of rural delivery addresses with street addresses. The incorrect placement of mailing addresses in residential Area 1 municipalities prior to about 2002 overestimated the number of cancers occurring among residents living in close proximity to the nuclear facilities and, correspondingly, underestimated the number among Area 2 residents. Summing Area 1 and Area 2 data showed that there was no change in cancer rates over time. These results are consistent with previous studies indicating that living in municipalities near the former Apollo-Parks nuclear facilities was not associated with an increase in cancer occurrence.**

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Key words: uranium; plutonium; health effects; epidemiology

INTRODUCTION

THREE STUDIES have evaluated cancer rates in communities near the former Apollo and Parks nuclear facilities in western Pennsylvania where uranium and plutonium had been processed for commercial and naval reactor use from the late 1950's until about 1980 (PDH 1986, 1996; Boice et al. 2003b; U.S. NRC 1995). The facilities were located about 40 miles northeast of Pittsburgh. Our previous study assessed cancer incidence rates for the years 1993–1997, or nearly 40 years after the plants had begun operation in 1957 and 1960, respectively (Boice et al. 2003b). The rates of cancer were evaluated among the approximately 17,000 persons living in one of eight minor civil divisions (MCDs) (Area 1, Fig. 1) encompassing or within one mile of these nuclear facilities. These MCDs included Apollo, North Apollo, East Vandergrift, Oklahoma, Vandergrift, Leechburg, Parks, and Hyde Park. The mailing addresses of 935 residents diagnosed with cancer who presumably lived in Area 1 were obtained from the Pennsylvania Department of Health (PDH). Because mailing addresses in small rural areas do not always reflect the actual town or municipality of residence, each of the 935 addresses was placed into the correct MCD of residence by contacting area postmasters and using Census Bureau information, street

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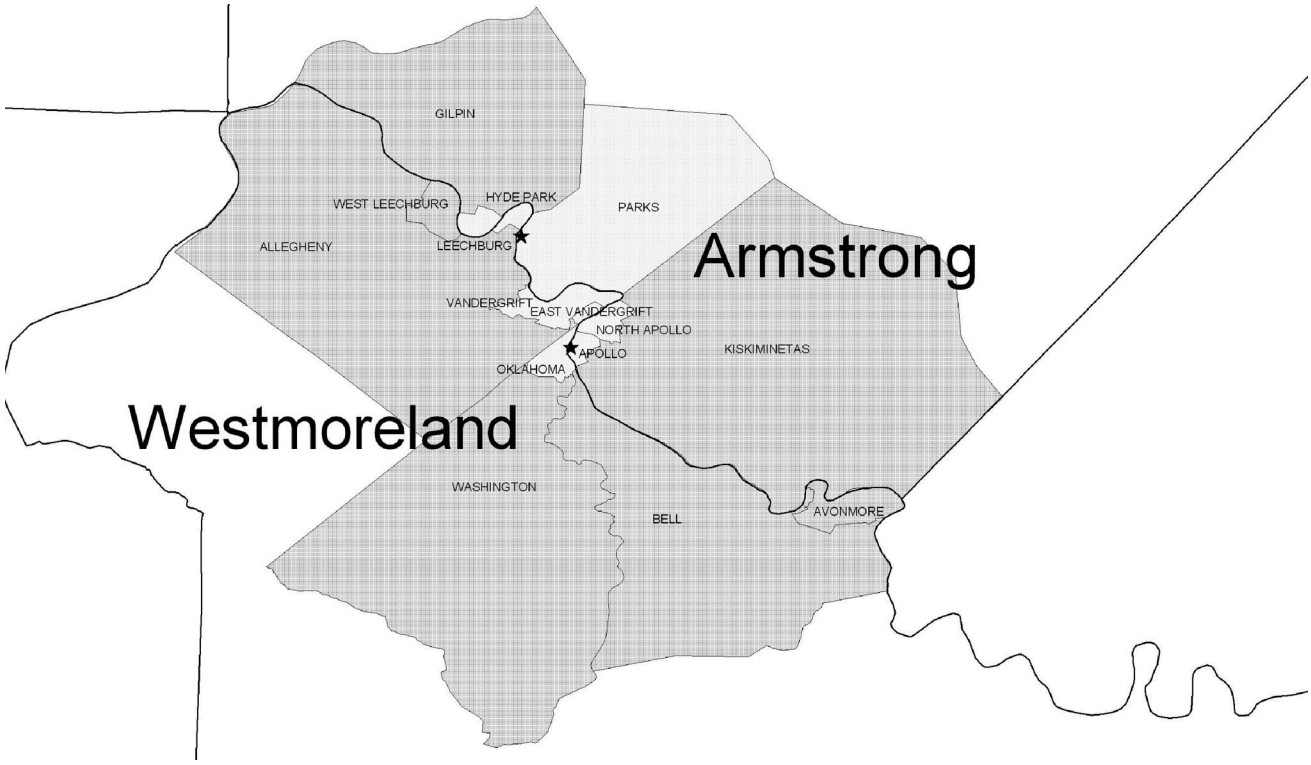

Fig. 1. Area 1 municipalities (MCDs: Apollo, North Apollo, East Vandergrift, Oklahoma, Vandergrift, Parks, Leechburg, and Hyde Park) within one mile of either of the Apollo or Parks nuclear materials processing facilities (designated by stars) and Area 2 municipalities (MCDs: Gilpin, Kiskimenetas, Allegheny, Avonmore, Bell, Washington, and West Leechburg) at somewhat greater distance (PDH 1996). The Kiskiminetas River forms the border between Armstrong and Westmoreland counties.

maps and aerial photographs. Consistent with previous studies conducted by the PDH (PDH 1986, 1996), up to 40% of the mailing addresses of patients reported to have cancer were incorrectly assigned to Area 1 municipalities. After excluding such patients, 581 cancers remained in contrast to 574.0 expected [Standardized Incidence Rate (SIR) 1.01; 95% confidence interval (CI) 0.93–1.10]. Based upon knowledge of the tissues where uranium or plutonium might deposit after intake (ICRP 1995a, 1995b; Leggett 1989), cancers of the lung (SIR 0.88), kidney (SIR 1.05), non-Hodgkin lymphoma (SIR 1.10), liver (SIR 0.61), and bone (2 observed vs. 1.19 expected) were carefully evaluated but no statistically significant excesses were noted. Cancers of the female breast and thyroid and leukemia also did not show statistically significant increases, an expected finding since these tissues are not sites where uranium or plutonium would concentrate had there been internal exposure from any environmental contamination. Overall, no increase in cancer occurrence could be attributed to living near the two former nuclear materials processing facilities. However, misleading elevations in cancer occurrence would have been suggested had mailing addresses not been evaluated and adjustments not made for persons with Area 1 mailing addresses who lived elsewhere.

In this updated report, we extended the previous studies for an additional seven years by evaluating cancer incidence in the eight Area 1 municipalities over the years 1998 through 2004. The previous study data from 1984 through 2004 are also summarized. Further, aggregate cancer incidence data from 1990 through 2004 were evaluated for residents presumed to have lived in Area 1 and for residents presumed to have lived within seven adjacent MCDs, but more distant from the nuclear facilities (designated as Area 2, Fig. 1) based on mailing address alone.

METHODS

Exposure potential

The Apollo facility began operating in 1957. Its primary function was to produce uranium fuel for commercial and naval reactor use. This involved the chemical conversion of both low-enriched uranium and high-enriched uranium hexafluoride gas into uranium dioxide powder. Other functions included production of fuel

pellets, scrap recovery of uranium, fuel fabrication research, and limited fabrication of fuel rods and assemblies. After the uranium processing and fuel production activities were phased out in 1983, the site was involved in the decontamination of equipment, volume reduction of radioactive wastes, storage of contaminated materials, and laboratory analyses. These activities involved a number of different chemical processes. Liquid effluents were discharged into the river following treatment and later into the municipal sewer system. Similarly, airborne effluents were treated before being released to the atmosphere through roof stacks. Filtration in the stacks included scrubbers and high efficiency particulate air (HEPA) filters to limit the amount of radioactive particles and any other chemicals released to the environment. The wind patterns were primarily from the southwest. The Apollo facility was decommissioned and decontaminated and no longer exists. In 1997, the Nuclear Regulatory Commission determined that the Apollo site was safe for other uses (U.S. NRC 1997). The primary operation of the Parks township site was the fabrication of plutonium fuel, the preparation of high-enriched uranium fuel, and the irradiation and testing of fuel samples. The Parks site was also used for land burial of low-level radioactive wastes from about 1960 until 1970 when the burial of wastes ceased. Neither facility handled high-level radioactive wastes and neither facility operated a nuclear reactor. Neither facility was involved in reprocessing of spent nuclear fuel.

Measurements of radioactivity levels made by the University of Pittsburgh (CHMR 1994) near the Apollo facility detected some uranium isotopes that are components of nuclear fuel, although overall levels of radioactivity were stated to be typical of those found in natural soils and rocks in this area. For other radionuclides associated with nuclear fuel, the radioactivity levels were near or below the limits of detection. Plutonium was not detected at all and ^{137}Cs was found at levels that are typical for U.S. soils. It was stated that ^{40}K, which occurs naturally, was the predominant radionuclide found in the soil samples.

The radionuclides of particular interest are thus uranium and plutonium because these are the primary radionuclides used at the Apollo and Parks nuclear processing and manufacturing facilities.

Aggregate counts by municipality (MCD)

Based on mailing addresses reported to the Pennsylvania Cancer Registry, aggregate counts of reported cancers in Area 1 and Area 2 MCDs for the years 1990–2004 were obtained from the PDH "Epidemiologic Query and Mapping System (EpiQMS)" Web site (http://app2.health.state.pa.us/epiqms). The eight Area 1 proximal MCDs had been previously selected by PDH (1986, 1988, 1996) as Apollo, North Apollo, East Vandergrift, Oklahoma, Vandergrift, Leechburg, Parks and Hyde Park (Fig. 1). The seven adjacent but more distant Area 2 MCDs had been selected as Gilpin, Kiskiminetas, Allegheny, Avonmore, Bell, Washington, and West Leechburg. Cancer counts in Area 1 and Area 2 were plotted for each year from 1990 to 2004.

Cancer identification

Cancer diagnostic information and mailing addresses for persons reported to have developed cancer from 1998 through 2004 and presumed to have lived within Area 1 were provided by the Pennsylvania Bureau of Health Statistics. Approval from the PDH for access to protected data was received, after assuring confidentiality of the cancer incidence data. MCD codes and U.S. postal ZIP codes were used by the PDH to identify 886 persons diagnosed with cancer who may have resided within Area 1 based on mailing addresses listed in patient records. Date of birth, date of cancer diagnosis, kind of cancer (ICDO-3 code), race, sex, and mailing address were obtained for each of the 886 persons. In addition, a longitude/latitude point coordinate, along with a measure of the precision of the geocoded address was obtained. For example, a "1" indicated an accurate geocoded address based on a known street address, whereas a "4" indicated greater uncertainty, e.g., that latitude/longitude coordinate was based on the location of the centroid of the reported postal ZIP code and not an actual street address.

Residential validation

Residence within Area 1 had to be validated because patient mailing addresses, as obtained by the Pennsylvania Cancer Registry from the medical records of reporting hospitals or medical facilities, often did not correspond with the actual town or municipality of residence. Mailing addresses in rural areas include "rural delivery" (RD) and "post office box" (PO Box) addresses for persons who do not always live in the same town where the post office is located. For example, RD routes often cross MCD boundaries and a person with an Apollo PO Box or RD mailing address might actually live in an adjacent municipality such as the Kiskiminetas or Allegheny townships and not in the Apollo borough where the post office is located. The seven outlying and more rural Area 2 MCDs had fewer post offices than the eight Area 1 MCDs near the Apollo-Parks facilities. Mail for persons living in Area 2 was often delivered, based on mailing address, first to an Area 1 post office and then delivered to the actual Area 2 residence. It was rarely if ever the case that the more distant Area 2 post offices would receive mail based on mailing address that would require delivery for persons whose actual residences were in the Area 1 towns. Among the 886 address for persons with cancer, 54 (6%) were PO

Boxes and 125 (14%) were on RD routes that were not necessarily within the boundaries of Area 1. By not correcting mailing addresses to actual physical address, the number of persons with cancer living near the Apollo-Parks facilities would be overestimated and the number living in adjacent, but more distant rural areas (Area 2) would be underestimated. Previously, PDH reported that using mailing address instead of actual address would seriously bias cancer rates for a given municipality, and failure to correct residence information could invalidate a study (PDH 1988).

To validate whether mailing addresses were located within Area 1, all street addresses not already geocoded by PDH were geocoded to a specific latitude/longitude coordinate location using the geocoding services provided by TeleAtlas (www.geocode.com). The location coordinates were then entered into an ArcView (ESRI, http://www.esri.com) Geographic Information Systems (GIS) mapping system to determine whether the location occurred within the Area 1 boundaries. ArcView shape files of MCD boundaries were obtained from the U.S. Census Bureau Web site. Street addresses that could not be geocoded (due to a street misspelling, invalid address, etc.) and all PO Box and RD addresses were provided to the postmasters of the six U.S. post offices serving the eight Area 1 municipalities. The postmasters classified each address as occurring within or not within the boundaries of Area 1 (see also methods section in Boice et al. 2003c for a detailed discussion). Only one of the 866 mailing addresses could not be confirmed as residing within or not within the eight Area 1 MCDs.

Population estimates

Five year age-, sex- and race-specific population estimates from the 2000 Census for Area 1 residents were extracted from Summary Tape Files available from the U.S. Census Bureau ftp site (directory/Census_2000/datasets/Summary_File_1/Pennsyvania at ftp2.census.gov). Incorrect residential designation was unlikely since census data are based on actual residence and not mailing address. The Area 1 population data (denominator) based on actual residence from the census were taken as correct, whereas the cancer incidence counts (numerator) based on mailing address had to be corrected to correspond to actual residence within these municipalities as described above. If this correction had not been made an erroneously high cancer rate might have been ascribed to residents in Area 1 municipalities.

Statistical methods

The observed number of cancer cases in Area 1 residents was taken as the number of residents who were diagnosed with cancer between 1998 and 2004 with valid Area 1 residential addresses. The number of expected cancer cases was calculated by multiplying the annual age-, sex-, and race-specific incidence rates from the Commonwealth of Pennsylvania for the years 1998–2004 (PDH 2007) by the corresponding population estimates of the eight Area 1 MCDs obtained from the Census Bureau. The SIR is taken as a measure of relative risk and was computed as the ratio of the observed to expected numbers of incident cancers. Because of the small number of non-whites residing in these areas (about 2–3% of the population), SIRs were only calculated for whites. Ninety-five percent CIs about the SIR were computed by assuming the observed number to be distributed as a Poisson variable (Bailar and Ederer 1964). A 95% CI that contains 1.0 is usually taken to mean that the observed number of cancers in the study was not statistically significantly different from the number expected.

RESULTS

Fig. 2 shows the number of incident cancers from publically available data sources (uncorrected for proper residential address) reported to have occurred each year from 1990 to 2004 among persons presumed to be living in Areas 1 and 2 MCDs (PDH 1996). A steady decrease in the number of reported cancers based on mailing addresses (but not necessarily actual residence) is seen for Area 1 residents in contrast to a steady rise in the number of cancers reported for Area 2 residents. The number of reported cancers in Area 1 decreased from 210 to 112 despite the aging of the population which would be expected to result in a net increase in the occurrence of cancers. In contrast, the corresponding number in Area 2 increased from 48 to 124. There was no overall change in cancer occurrence for the years 1990 through 2004 when data for Area 1 and Area 2 were combined.

The use of RD addresses over the years has decreased to facilitate emergency services (911 responses), e.g., in 1998 there were 34 RD addresses among the cancer registrations assigned to the Area 1 municipalities whereas in 2004 there were only five. Further, geocoding procedures available to the PDH have improved, especially after 2001. Geocoding is the process by which latitude/longitude coordinates are assigned to street addresses, and as such, the city listed on current mailing addresses of cancer patients has become a better indicator of actual town or MCD of residence than in years past. For the most recent years with available data (2002–2004) there were 318 cancers reported to have occurred in Area 1. Based on cancer rates in the general population of Pennsylvania, the expected number of cancers was 321. That is, living in the municipalities near the former uranium and plutonium processing facilities was not associated with an overall increase in cancer occurrence when proper account is taken of the difference between mailing address and actual residential location.

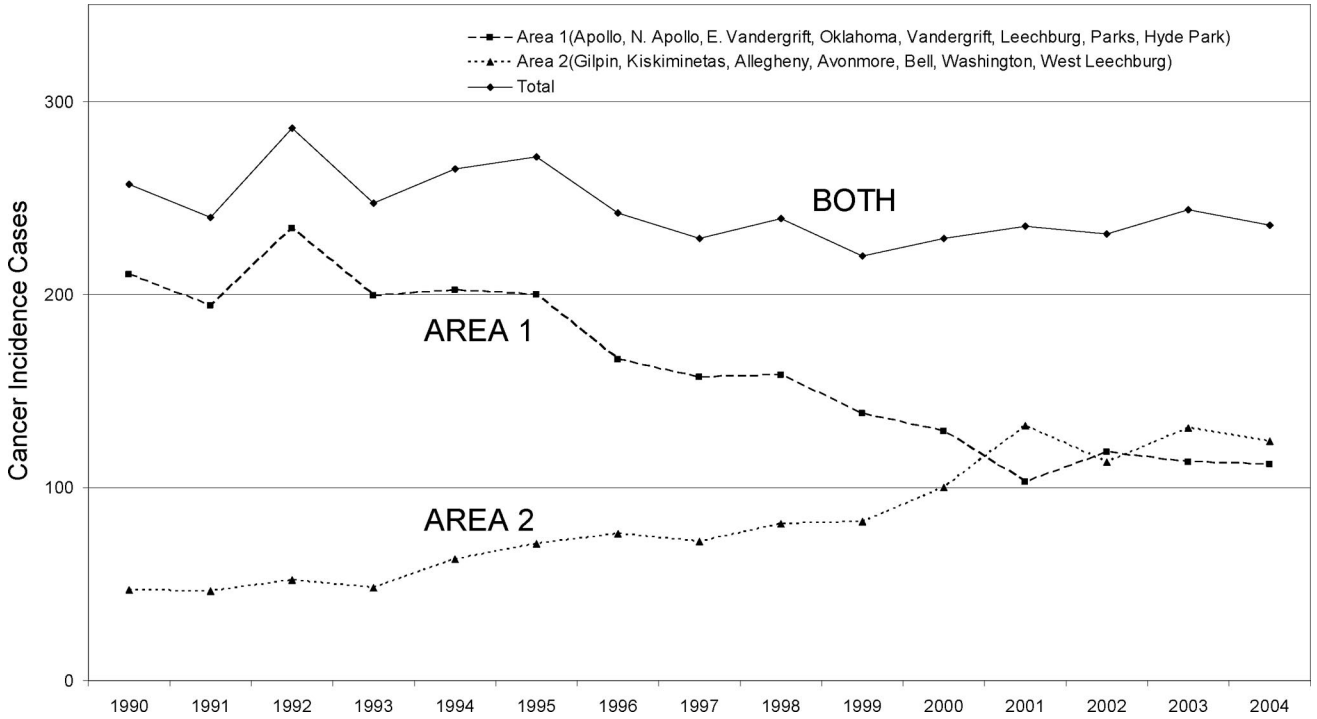

Fig. 2. Number of cancer cases per year among residents presumed to have lived in one of eight Area 1 municipalities (MCDs) within one mile of the Apollo or Parks nuclear materials processing facilities or in one of seven Area 2 municipalities (MCDs) at greater distance from the facilities (Fig. 1) based on mailing address and not actual residential address for the years 1990 through 2004 (PDH 2007). These cancer counts are from publically available data sources and the changes over time reflect the improved reporting and geocoding of addresses by the Pennsylvania Department of Health.

Despite the improvements in assigning mailing addresses to MCD of residence, the publicly available number of aggregate cancer cases in Area 1 for 2002–2004 is probably somewhat overestimated since not all the PO Box addresses and the few remaining RD addresses would be expected to be geocoded correctly, i.e., the latitude/longitude coordinates would have to have been estimated by the PDH. For those PO Box or RD mailing addresses with only a ZIP code provided (about 40), the "centroid" of the ZIP code (center of the ZIP code area) was used to assign the geocoded MCD location in the absence of an actual street address. Since the centroid of a ZIP code does not necessarily lie within the MCD of actual residence, contact with local postmasters was needed to more accurately place all mailing addresses of cancer patients within the actual town or MCD of residence.

Table 1 presents the reported number of cancer cases during 1996–2004 among residents of the eight proximal MCDs and the number confirmed by geocoding and postmaster contact. Overall, 137 of the 866 mailing addresses (or 15.8%) were incorrect with respect to actual location in Area 1. Discrepancies occurred most often for RD and PO Box addresses and when street addresses were missing.

The observed and expected numbers of cancer incident cases in Area 1 between 1998 and 2004 are presented in Table 2. Cancer patients with Area 1 mailing addresses but determined not to be living in Area 1 MCDs ($n = 137$) were excluded from analyses relating to Area 1 residence. The number of observed cancers based on confirmed addresses ($n = 708$) was very similar to the number expected (728.4) based on the cancer incidence rates of the general population of Pennsylvania (SIR 0.97; 95% CI 0.90–1.05). Cancer sites of *a priori* interest were not found statistically to be significantly increased or decreased: cancers of the lung (SIR 1.05; 95% CI 0.87–1.26; $n = 112$); liver (SIR 0.95; 95% CI 0.35–2.06; $n = 6$); kidney (SIR 0.96; 95% CI 0.58–1.50; $n = 19$); or bone (2 observed and 1.02 expected). Similarly, cancers that have been linked to penetrating radiations were not found statistically to be significantly increased or decreased: leukemia (SIR 1.01; 95% CI 0.60–1.60; $n = 18$) and cancers of the female breast (SIR 0.88; 95% CI 0.71–1.08; $n = 91$). A deficit of thyroid cancer (SIR 0.46; 95% CI 0.17–1.01; $n = 6$) was close to statistical significance. Cancers other than the main 26 cancers listed by the PDH (2007) occurred below expectation and the deficit approached statistical significance (SIR 0.83; 95% CI 0.60–1.12; $n = 42$). Cancer of the corpus uteri, a cancer not established as being caused by radiation (IARC 2000; UNSCEAR 2000; NRC 2006), occurred

Table 1. Number of reported and confirmed mailing addresses for 866 residents diagnosed with cancer (1998–2004) presumed to have lived within one of eight minor civil divisions (MCDs) near the two former nuclear materials processing facilities in Armstrong county, Pennsylvania.

Mailing address (town/city)[a]	Patient addresses within Area 1 MCDs		
	Reported[b]	Confirmed[c]	Percent confirmed
Near Apollo facility			
Apollo	137	98	71.5
North Apollo	62	53	85.5
E. Vandergrift	29	29	100.0
Vandergrift	443	415	93.7
Near Parks facility			
Hyde Park	24	24	100.0
Leechburg	158	105	66.5
Other	13	5	38.5
Total	866	729	84.2

[a] There were six post offices that delivered mail to persons residing in the eight Area 1 study municipalities (MCDs) and to persons with RD addresses residing in adjacent Area 2 MCDs.
[b] All mailing addresses were obtained from the Pennsylvania Department of Health.
[c] Only one of the 866 mailing addresses could not be confirmed as being within or not within one of the eight MCDs. Confirmation was by geocoding street addresses and contacting local postmasters.

above expectation and the increase was statistically significant (SIR 1.75; 95% CI 1.26–2.36; $n = 42$). For the 27 cancer categories evaluated, 12 were slightly above 1.0 and 15 were slightly below 1.0—a distribution consistent with the normal variation seen in general population statistics and with the play of chance when making so many comparisons.

Table 3 presents the patterns of cancer rates over the years 1984–2004 among white residents confirmed to have lived in Area 1. Data for 1984–1985 and 1986–1992 were

Table 2. Observed and expected cancers and standardized incidence rates (SIRs) among white residents in eight minor civil divisions (MCDs) near the two former nuclear materials processing facilities in western Pennsylvania, 1998–2004.

Cancer (ICD0-3)	Observed[a]	Expected[b]	SIR	95% CI
Buccal cavity and pharynx (C000–C148)	8	12.98	0.62	0.27–1.21
Esophagus (C150–C159)	8	7.62	1.05	0.45–2.07
Stomach (C160–C169)	12	11.16	1.08	0.55–1.88
Colon (C180–C189, C260)	76	71.04	1.07	0.84–1.34
Rectum and rectosigmoid (C199, C209)	20	25.24	0.79	0.48–1.22
Pancreas (C250–C259)	19	17.65	1.08	0.65–1.68
Larynx (C320–C329)	10	6.03	1.66	0.79–3.05
Trachea, bronchus, lung, pleura (C340–C349)	112	106.58	1.05	0.87–1.26
Melanoma of skin (C440–C449)	16	20.70	0.77	0.44–1.26
Female breast (C500–C509)	91	103.70	0.88	0.71–1.08
Cervix uteri (C530–C539)	4	5.10	0.78	0.21–2.01
Corpus uteri (C540–C559)	42	24.07	1.75[c]	1.26–2.36
Ovary (C569)	11	12.62	0.87	0.43–1.56
Prostate (C619)	90	96.72	0.93	0.75–1.14
Testis (C620–C629)	4	3.24	1.24	0.33–3.16
Urinary bladder (C670–C679)	44	40.76	1.08	0.78–1.45
Kidney and renal pelvis (C649, C659)	19	19.73	0.96	0.58–1.50
Brain and nervous system (C700–C729)	8	9.07	0.88	0.38–1.74
Thyroid (C739)	6	12.92	0.46	0.17–1.01
Non-Hodgkin lymphoma (C200, C202)[d]	26	30.40	0.86	0.56–1.25
Hodgkin lymphoma (C201)	5	3.85	1.30	0.42–3.03
Multiple myeloma (C203.0, C203.8)	7	7.64	0.92	0.37–1.89
Leukemias (C202.4, C203.1, C204.0–C208.9)	18	17.79	1.01	0.60–1.60
Soft tissue (C380, C470–C479, C490–C499)	2	3.77	0.53	0.06–1.91
Bones and joints (C400–C419)	2	1.02	1.96	0.22–7.06
Liver and interhepatic bile duct (C220–C221)	6	6.34	0.95	0.35–2.06
Other cancers	42	50.63	0.83	0.60–1.12
Total (C000–C809)	708	728.4	0.97	0.90–1.05

[a] Observed cancer cases were those confirmed as having lived within the Area 1 boundaries.
[b] Expected cancer cases were computed based on the Census Bureau population figures for Area 1 MCDs and overall cancer rates for residents in the Commonwealth of Pennsylvania.
[c] $p < 0.05$.
[d] ICD0-3 histology codes: M-9590 to M-9596, M-9670 to M-9729.

Table 3. Observed and expected numbers of cancers and standardized incidence rates (SIRs) among white residents confirmed to have lived in the eight Area 1 municipalities (or MCDs) near the two former nuclear facilities in western Pennsylvania, 1984–2004, by calendar period.

	Calendar year															
	1984–85[a]			1986–92[b]			1993–97[c]			1998–2004			Total			
Cancer (ICD0-3)	Obs	Exp	SIR	Obs	Exp	SIR	Obs	Exp	SIR	Obs	Exp	SIR	Obs	Exp	SIR	95% CI
Buccal cavity and pharynx (C000–C148)	5	6.4	0.78	23	23.4	0.91	6	10.2	0.59	8	13.0	0.62	42	53.0	0.79	0.57–1.07
Esophagus (C150–C159)	1	1.8	0.56	9	9.1	0.99	5	5.5	0.91	8	7.6	1.05	23	24.1	0.96	0.61–1.44
Stomach (C160–C169)	5	4.8	1.04	26	21.2	1.26	10	9.5	1.05	12	11.2	1.08	53	46.7	1.14	0.85–1.49
Colon (C180–C189, C260)	26	23.6	1.10	112	104.0	1.08	76	59.9	1.27	76	71.1	1.07	290	258.6	1.12	0.99–1.25
Rectum and rectosigmoid (C199, C209)	14	9.4	1.49	56	39.1	1.43[d]	25	24.0	1.04	20	25.2	0.79	115	97.7	1.18	0.97–1.41
Pancreas (C250–C259)	5	5.9	0.85	23	25.8	0.89	14	11.9	1.18	19	17.7	1.08	61	61.2	1.00	0.76–1.28
Larynx (C320–C329)	2	2.8	0.71	11	10.7	1.02	3	5.8	0.51	10	6.0	1.66	26	25.4	1.02	0.67–1.50
Trachea, bronchus, lung, pleura (C340–C349)	40	33.6	1.19	156	158.4	0.98	74	84.4	0.88	112	106.6	1.05	382	383.0	1.00	0.90–1.10
Melanoma of skin (C440–C449)	3	4.5	0.67	14	24.7	0.57[d]	9	12.7	0.71	16	20.7	0.77	42	62.6	0.67[d]	0.48–0.91
Female breast (C500–C509)	30	30.3	0.99	155	153.7	1.02	85	89.8	0.95	91	103.7	0.88	361	377.5	0.96	0.86–1.06
Cervix uteri (C530–C539)	6	2.1	2.86[d]	12	8.8	1.36	10	4.3	2.35[d]	4	5.1	0.78	32	20.3	1.57[d]	1.07–2.22
Corpus uteri (C540–C559)	13	8.0	1.63	41	32.2	1.27	17	18.8	0.91	42	24.1	1.75[d]	113	83.1	1.36[d]	1.12–1.64
Ovary (C569)	4	4.5	0.89	22	20.2	1.09	9	10.7	0.84	11	12.6	0.87	46	48.0	0.96	0.70–1.28
Prostate (C619)	13	22.3	0.58[d]	145	134.6	1.08	81	83.2	0.97	90	96.7	0.93	329	336.8	0.98	0.87–1.09
Urinary bladder (C670–C679)	12	10.9	1.10	63	50.3	1.25	36	30.2	1.19	44	40.8	1.08	155	132.1	1.17	0.99–1.37
Kidney and renal pelvis (C649, C659)	4	4.3	0.93	25	21.6	1.16	14	13.3	1.05	19	19.7	0.96	62	58.9	1.05	0.81–1.35
Brain and nervous system (C700–C729)	2	3.2	0.63	8	13.6	0.59	3	6.7	0.45	8	9.1	0.88	21	32.6	0.64[d]	0.40–0.99
Thyroid (C739)	2	1.9	1.05	4	8.4	0.48	3	5.2	0.57	6	12.9	0.46	15	28.4	0.53[d]	0.30–0.87
Non-Hodgkin lymphoma (C200, C202)	5	6.9	0.72	26	36.2	0.72	23	20.9	1.10	26	30.4	0.86	80	94.4	0.85	0.67–1.06
Hodgkin lymphoma (C201)	1	1.3	0.77	3	5.0	0.60	1	2.7	0.37	5	3.9	1.30	10	12.9	0.78	0.37–1.43
Mutiple myeloma (C203.0, C203.8)	4	2.3	1.74	11	11.5	0.95	11	5.8	1.91	7	7.6	0.92	33	27.3	1.21	0.83–1.70
Leukemias (C202.4, C203.1, C204.0–C208.9)	3	5.7	0.53	20	25.5	0.79	18	12.4	1.45	18	17.8	1.01	59	61.4	0.96	0.73–1.24
Total (C000–C809)	230	214.8	1.07	966	940.0	1.03	581	574.0	1.01	708	728.4	0.97	2,573	2,534.2	1.02	0.98–1.06

[a] The SIRs for 1984–1985 are from Table 2 of PDH (1986) and Table 9 of PDH (1996) for invasive cancers.
[b] The SIRs for 1986–1992 are from Table 7 and Table 9 of PDH (1996) for invasive cancers.
[c] The SIRs for 1993–1997 are from Table 3 of Boice et al. (2003c) for invasive cancers.
[d] $p < 0.05$.

derived from studies conducted by the PDH (PDH 1986, 1996), data for 1993–1997 were derived from the study conducted by Boice et al. (2003c), and data for 1998–2004 were derived from the current study. For all cancers together, the SIRs remained relatively stable over the 21-y period, from 1.07 in 1984–1985 ($n = 230$) to 0.97 in 1998–2004 ($n = 708$). For all periods, the total number of cancers ($n = 2,573$) was essentially the same as the number expected (2,534.2) based on the prevailing cancer incidence rates in the general population of Pennsylvania (SIR 1.02; 95% CI 0.98–1.06).

For cancer sites of *a priori* interest, there were no statistically significant high or low SIRs for any time interval (Table 3), nor were the SIRs for all time intervals combined statistically significant: lung cancer (SIR 1.00; $n = 382$) or kidney cancer (SIR 1.05; $n = 62$). Similarly, there were no statistically significant high SIRs for any time internal for cancers that have been linked to penetrating radiations, nor were the SIRs for all time intervals combined statistically significant: female breast cancer (SIR 0.96; $n = 361$) or leukemia (SIR 0.96; $n = 59$). A deficit of thyroid cancer, however, was statistically significant (SIR 0.53; $n = 15$). Two female genital cancers were increased overall and the excesses were statistically significant: cancer of the cervix (SIR 1.57; $n = 32$) and cancer of the uterus (SIR 1.36; $n = 113$). Neither of these cancers, however, have been established as being caused by radiation (IARC 2000; UNSCEAR 2000; NRC 2006), and the patterns of increased and decreased risks over time were erratic and not consistent with the long latency distributions which might be associated with environmental exposures. Two cancers

known to be caused by radiation were decreased overall and the deficits were statistically significant: cancer of the thyroid as previously mentioned and cancer of the brain (SIR 0.64; $n = 21$); the patterns of risk over time were consistently low for these two cancers. Of the 22 individual cancers presented in Table 3, the overall SIR was equal to or above 1.00 for 11 cancers and below 1.00 for 11 cancers, i.e., a distribution consistent with the play of chance when making many comparisons of population data.

DISCUSSION

Counts of cancer incident cases based on mailing address from 1990 through 2004 and obtained from the publicly available data sources of the PDH showed a gradual decrease in reported cancer cases among persons presumed to have lived in Area 1 and within one mile of either the Apollo or Parks nuclear materials processing plants, leveling off around 2002. In contrast, persons presumed to have lived in Area 2, adjacent to Area 1 but more distant from the nuclear materials processing facilities, showed a gradual rise in the reported number of cancers over the years. When both Area 1 and Area 2 data were summed, the number of cancers per year remained essentially constant. These patterns suggest an improved assignment of MCD of actual residence, likely due to a decrease in the use of RD addresses and a more accurate geocoding procedure implemented by PDH over the years. These conclusions were confirmed for the years 1998–2004 by contacting local postmasters servicing the Area 1 MCDs and by geocoding street addresses obtained from the PDH. Over 15% of the mailing addresses were incorrect in that they did not correspond to the Area 1 municipalities for which they had been assigned. The rates of confirmation were highest for mailing addresses with street names and lowest for RD and PO Box addresses. Using confirmed MCD of residence, the 708 cancer patients living in Area 1 for 1998–2004 were as expected (728.4) based on general population cancer rates for Pennsylvania citizens. These analyses confirm the previously published reports by the PDH and others that cancer incidence around the Apollo-Parks facilities is not different from the cancer incidence in other regions of Pennsylvania (PDH 1996; Boice et al. 2003c).

Strengths and limitations

The study has several strengths. All data were collected previously by public health officials, and residence within specific municipalities or MCDs was determined from postal officials as part of their normal activities, from information available from the U.S. Census Bureau and from commercially available Internet geocoding sites and software packages. Thus there was minimal chance for bias based on knowledge of the study hypothesis. The Area 1 MCDs were geographically small and all within a mile from either of the nuclear materials processing facilities, so that any local increases in cancer rates related to plant operations conceivably might be detected had they occurred. The sample size was sufficient to exclude total cancer risks greater than 1.05, or a 5% increase, with 95% confidence. The likelihood that former workers also lived near the facilities increased the chance of detecting a community effect if worker exposures were assumed to be related to increased cancer rates; i.e., worker exposures to any nuclear processing materials would be anticipated to be larger than those experienced in the surrounding communities. The period of almost 50 y after the plants began operating in 1957 and 1960 was such that any induced cancers with long latency periods had the possibility of being detected. The patterns of cancer rates over time could be evaluated for changes. Finally, the availability of cancer incidence data rather than mortality enhanced the quality of the data being analyzed.

There are, however, limitations characteristic of any descriptive correlation study. It is unknown whether the persons living in the communities of interest had lived there for long periods of time or whether they received any measurable radiation exposure associated with industrial activities. This is a common problem associated with correlation studies, where exposure information is assumed for groups and is not known for individuals. Uranium isotopes typical of nuclear fuel were detected in soil samples taken around the Apollo nuclear processing facility, although overall levels of radioactivity were stated in a 1994 University of Pittsburgh report to be typical of levels found in this area (CHMR 1994). Information on potentially important confounding influences, such as cigarette smoking, also was not known.

Differential screenings and rates of detection for cancers could also have affected findings. An increase in uterine cancer was seen that was statistically significant in contrast to a slight deficit seen in previous years. Cervical cancer occurred below expectation but was significantly elevated in previous years. The patterns of cervical and uterine cancer over the years in these communities suggest that the rate of diagnoses may have been affected by the rate of detection or screening (PDH 1996). That is, if a population receives more screening procedures than the comparison population, incorrect or biased associations might result. Uterine and cervical cancers are not consistently found to be increased following radiation exposure (UNSCEAR 2008; Boice 2006).

Our estimates of the total resident population within Area 1 were based on the 2000 Census. In or out migration may have resulted in changes for the 1998–

2004 study period, but the changes were seen to be small based on the 1990 and 2000 Census figures. Specifically, in 1990 there were 16,772 persons living in Area 1, and in 2000 the total population had decreased only slightly to 15,956 (or 4.9%). The population figures for Area 2 also showed only a small decrease from 28,648 in 1990 to 27,493 in 2000 (or 4.0%). For both Area 1 and Area 2, the population over the age of 65 y increased slightly from 7,776 to 7,854 (or 1.0%) whereas the younger population decreased slightly from 37,644 to 35,585 (or 5.5%) between 1990 and 2000. Population changes of the elderly would be important since they likely had more of an opportunity for exposure to any environmental radiation from plant operations which began as early as 1957. The percentage of persons over the age of 65 y was seen to increase slightly, however, and suggests that migration is unlikely to be a major factor.

General population rates are often used in epidemiologic studies for comparison purposes because they are readily available and provide stable estimates of expected numbers. Adjustments can also be made for differences in age, race, and sex but not generally for other cancer risk indicators. Differences in socioeconomic status, access to medical care and diagnostic facilities, urbanization, and smoking habits, for example, could influence the validity of the comparison. However, except for occupational, medical and a few other groups where selection of healthy or unhealthy persons becomes an issue, the use of the general population for comparison with community data is rarely a problem, especially when cancer occurrence over time can be evaluated. The absence of any noticeable trends in cancer rates over the years 1984 to 2004 in the Apollo-Parks proximal municipalities (PDH 1986, 1996; Boice et al. 2003c) supports the notion that the presence of the two former nuclear materials processing facilities has not adversely affected the health of the local populations with respect to cancer.

We did not analyze the incident cancers that were excluded from Area 1 because of incorrect placement, even though many lived in Area 2. This was because we were not evaluating cancer occurrence in these more distant Area 2 MCDs or using them for comparison, i.e., the referent group was the general population of Pennsylvania. Similarly, the incorrect MCD assignments were overwhelmingly in one direction, i.e., those living in Area 2 were incorrectly assigned to be living in Area 1 based on their mailing address, but few if any persons living in Area 1 had mailing addresses in Area 2. This was because the excluded addresses were mainly those on RD routes or with PO Boxes, and there was little likelihood or reason for someone living in one of the proximal (Area 1) towns to have their mail delivered elsewhere in one of the more distant and rural (Area 2) municipalities. In contrast, those living in the more distant, larger and more rural (95% vs. 50% rural) Area 2 MCDs did not have as many local post offices for mail delivery and thus their mail often had an RD address associated with an Area 1 post office ZIP code. Fig. 2 also shows that as the mailing addresses have changed over time to correspond with actual municipality of residence (in response to 911 issues); the correction has always been in one direction, i.e., the numbers of cancers assigned to Area 1 decreased and the number of cancers assigned to Area 2 increased reflecting the improvements in reporting and geocoding of the addresses by the PDH.

CONCLUSION

Persons living in municipalities within a mile of former nuclear materials processing and fabrication facilities in Pennsylvania and potentially exposed to any uranium or plutonium released into the proximal environment were not found to have elevated rates of cancer over the years 1998 through 2004. Incorrect conclusions, however, would have been made if mailing addresses from patient records were not confirmed as being located within the proximal Area 1 MCDs, and study results would be invalid (PDH 1988). The municipality or MCD assigned to a mailing address by PDH cancer registration data was found to be incorrect over 15% of the time for the years 1998–2004, mainly because RD and PO Box addresses did not reflect actual MCD of residence. After assigning cancer cases to their correct MCD of residence, there was no evidence for increased cancer rates among the populations living near the former nuclear facility sites. These data were also consistent with previous municipality studies of cancer incidence over the years 1984 through 1997 (PDH 1996; Boice et al. 2003c), and with county analyses of mortality and cancer incidence data (Boice et al. 2003b, 2009). Finally, these negative results are consistent with epidemiologic studies that find no convincing evidence that uranium is a cause of cancer (UNSCEAR 2008; ATSDR 1999; Harley et al. 1999; IOM 2000; IARC 2001; Royal Society 2001; Auvinen et al. 2002; Pinkerton et al. 2004; Kurttio et al. 2006; Boice et al. 2003a, 2007, 2008) and that the levels of plutonium needed to cause specific cancers are enormous (Voelz et al. 1997; Omar et al. 1999; IARC 2001; Boice 2006). It can be concluded that the Apollo-Parks nuclear materials processing facilities had no measurable effect on the cancer rates in the surrounding areas.

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