Childhood cancer and nuclear power plants in Switzerland: A census-based cohort study

Webappendix 2 – Additional Analyses

Content

Incidence of childhood cancer during study period

Table E 1: Observed cancer diagnoses and incidence rates in the resident cohort (per 100'000 person years) among children aged 0-15 years in Switzerland, 1985 – 2009.

		All cancers			Leukaemia		
		Cases	IR	95% CI	Cases	IR	95% CI
Gender	Male	2278	14.22	(13.65-14.81)	773	4.82	(4.50-5.18)
	Female	1812	11.88	(11.34-12.44)	572	3.75	(3.45-4.07)
Calendar year	1985	119	10.19	(8.51-12.19)	51	4.37	(3.32-5.74)
	1986	107	9.22	(7.63-11.15)	42	3.62	(2.68-4.90)
	1987	107	9.26	(7.66-11.19)	38	3.29	(2.39-4.52)
	1988	119	10.25	(8.57-12.27)	54	4.65	(3.56-6.08)
	1989	110	9.41	(7.81-11.34)	31	2.65	(1.87-3.77)
	1990	146	12.27	(10.43-14.43)	52	4.37	(3.33-5.73)
	1991	155	12.79	(10.92-14.97)	59	4.87	(3.77-6.28)
	1992	167	13.48	(11.58-15.68)	51	4.12	(3.13-5.42)
	1993	170	13.48	(11.60-15.67)	58	4.60	(3.56-5.95)
	1994	187	14.63	(12.68-16.89)	59	4.62	(3.58-5.96)
	1995	144	11.14	(9.46-13.11)	49	3.79	(2.86-5.01)
	1996	170	13.09	(11.26-15.21)	55	4.24	(3.25-5.52)
	1997	189	14.54	(12.61-16.76)	61	4.69	(3.65-6.03)
	1998	169	12.99	(11.17-15.10)	51	3.92	(2.98-5.16)
	1999	179	13.70	(11.83-15.86)	57	4.36	(3.37-5.66)
	2000	178	13.61	(11.75-15.77)	58	4.44	(3.43-5.74)
	2001	179	13.89	(12.00-16.08)	57	4.42	(3.41-5.73)
	2002	207	16.06	(14.02-18.41)	61	4.73	(3.68-6.08)
	2003	202	15.70	(13.68-18.02)	57	4.43	(3.42-5.74)
	2004	195	15.22	(13.22-17.51)	62	4.84	(3.77-6.21)
	2005	201	15.78	(13.74-18.12)	65	5.10	(4.00-6.51)
	2006	181	14.30	(12.36-16.54)	49	3.87	(2.93-5.12)
	2007	178	14.10	(12.17-16.33)	66	5.23	(4.11-6.65)
	2008	172	13.60	(11.71-15.79)	58	4.59	(3.55-5.93)
	2009	159	12.57	(10.76-14.68)	44	3.48	(2.59-4.67)
Age at diagnosis	0	412	22.18	(20.14-24.43)	47	2.53	(1.90-3.37)
	1	372	19.86	(17.94-21.98)	119	6.35	(5.31-7.60)
	2	407	21.65	(19.64-23.85)	206	10.96	(9.56-12.56)
	3	349	18.11	(16.31-20.12)	172	8.93	(7.69-10.37)
	4	290	15.16	(13.51-17.01)	136	7.11	(6.01-8.41)
	5	261	13.34	(11.82-15.07)	98	5.01	(4.11-6.11)
	6	219	11.22	(9.83-12.81)	81	4.15	(3.34-5.16)
	7	215	10.77	(9.42-12.31)	70	3.51	(2.77-4.43)
	8	180	9.16	(7.92-10.60)	60	3.05	(2.37-3.93)
	9	151	7.68	(6.54-9.00)	42	2.14	(1.58-2.89)
	10	176	8.98	(7.75-10.41)	47	2.40	(1.80-3.19)
	11	192	9.64	(8.37-11.11)	56	2.81	(2.16-3.66)
	12	204	10.37	(9.04-11.90)	58	2.95	(2.28-3.82)
	13	252	12.59	(11.13-14.25)	59	2.95	(2.28-3.81)
	14	222	11.03	(9.67-12.58)	51	2.53	(1.93-3.34)
	15	188	9.13	(7.91-10.53)	43	2.09	(1.55-2.81)

Adjusting for potential confounders

The following figures show results for Poisson regression models adjusted for age at diagnosis, sex, calendar year and a single potential confounder at a time (see Webappendix 1 for data sources and variable definitions). Results are shown for the birth and resident cohort.

Adjusting for total background ionising radiation including cosmic, terrestrial and artificial sources

Figure E 1: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and total background radiation.

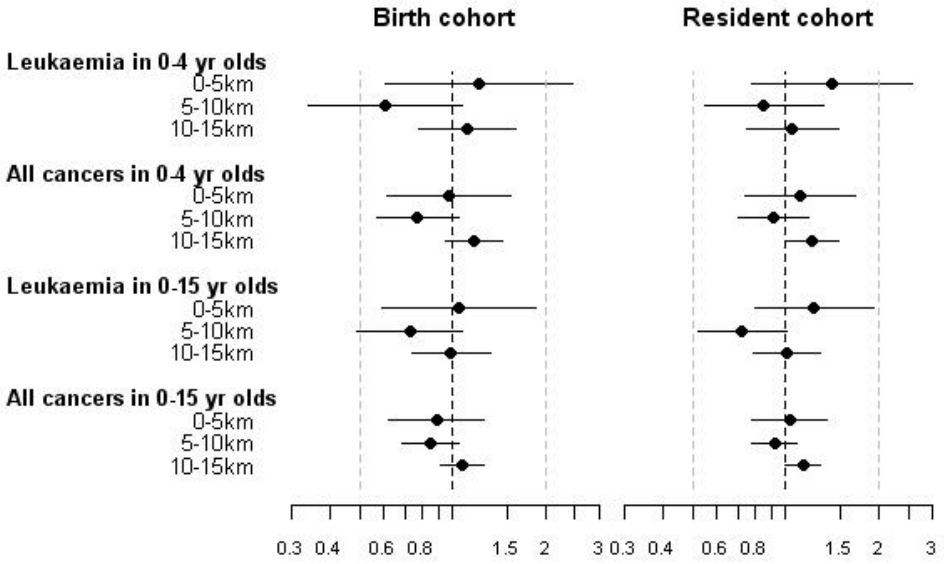
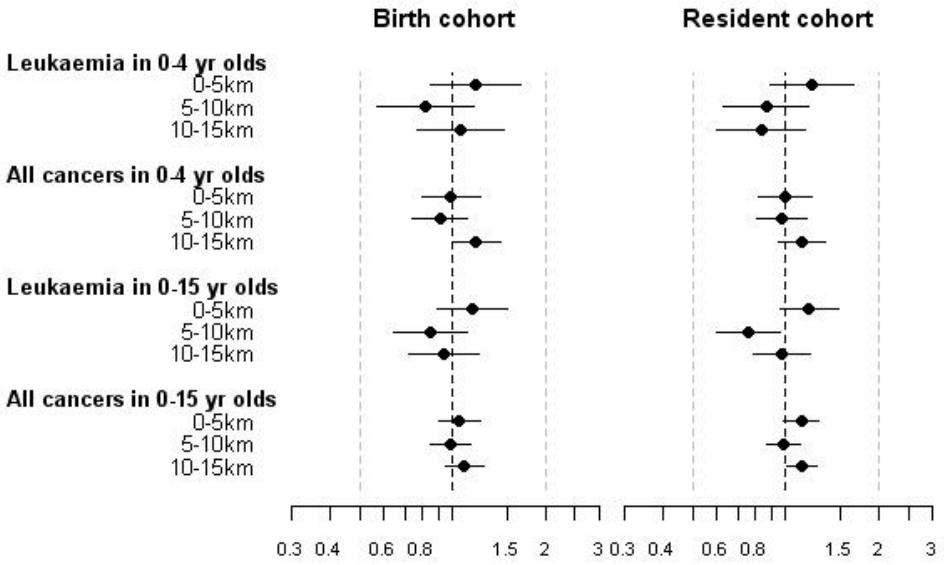


Figure E 2: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and total background radiation.



Adjusting for cosmic background ionising radiation

Figure E 3: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and cosmic background radiation.

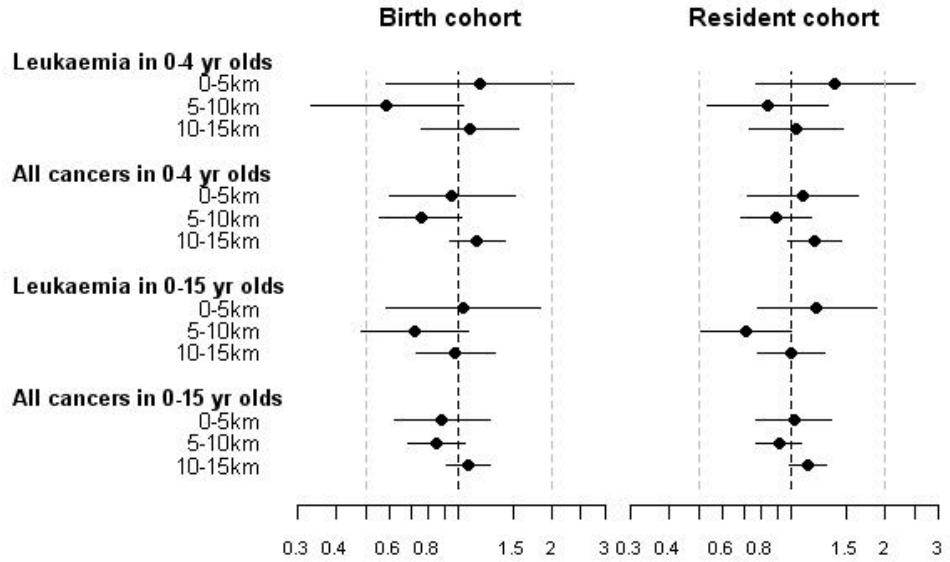
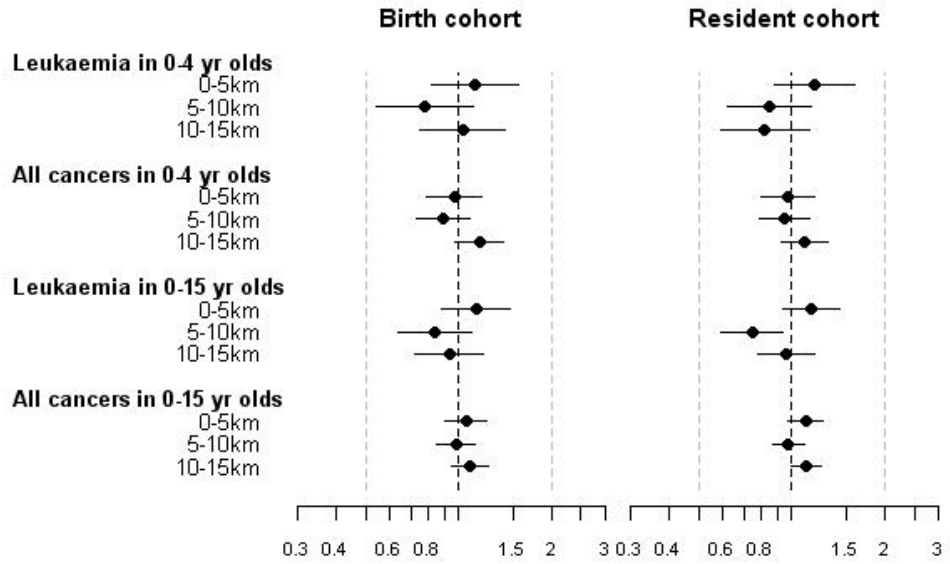


Figure E 4: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and cosmic background radiation.



Adjusting for terrestrial background ionising radiation

Figure E 5: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and terrestrial background radiation.

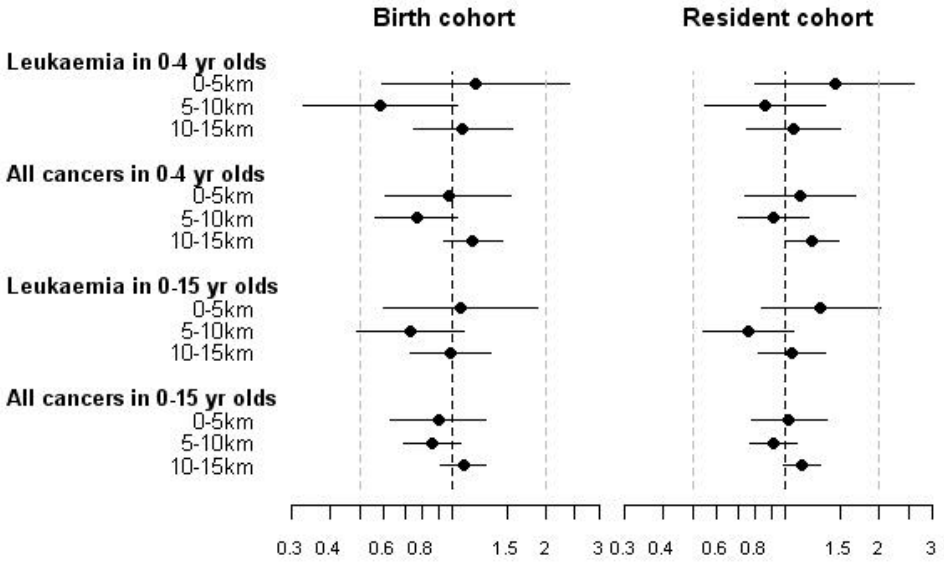
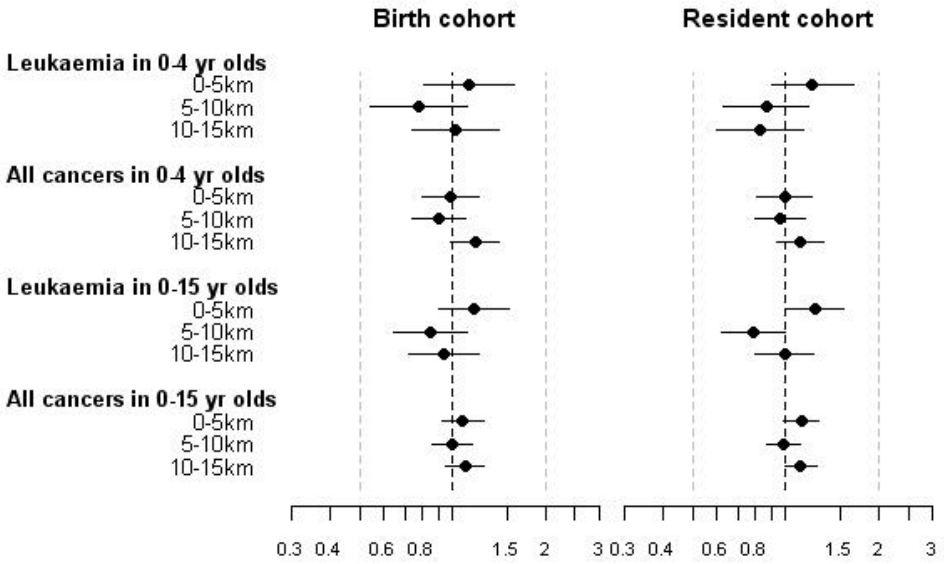


Figure E 6: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and terrestrial background radiation.



Adjusting for artificial background ionising radiation

Figure E 7: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and artificial background radiation.

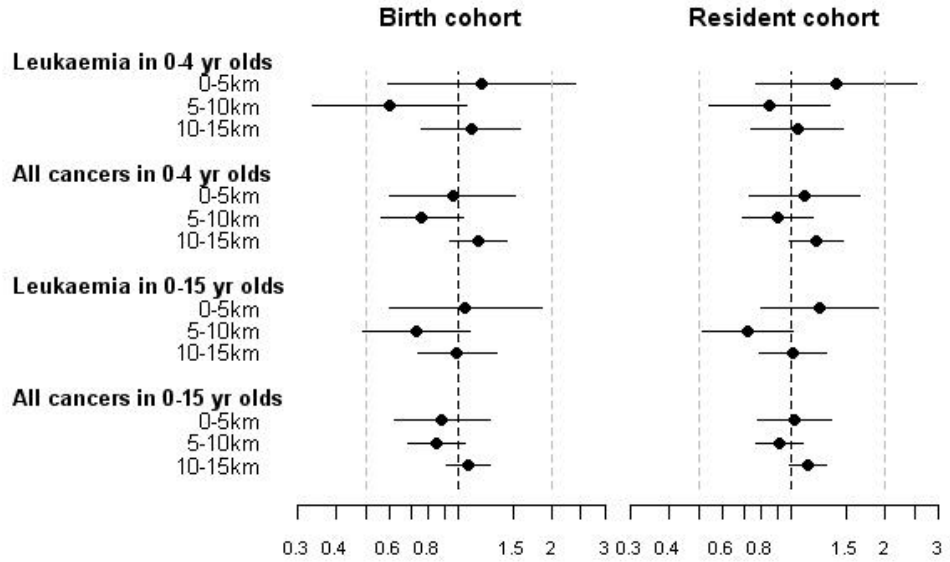
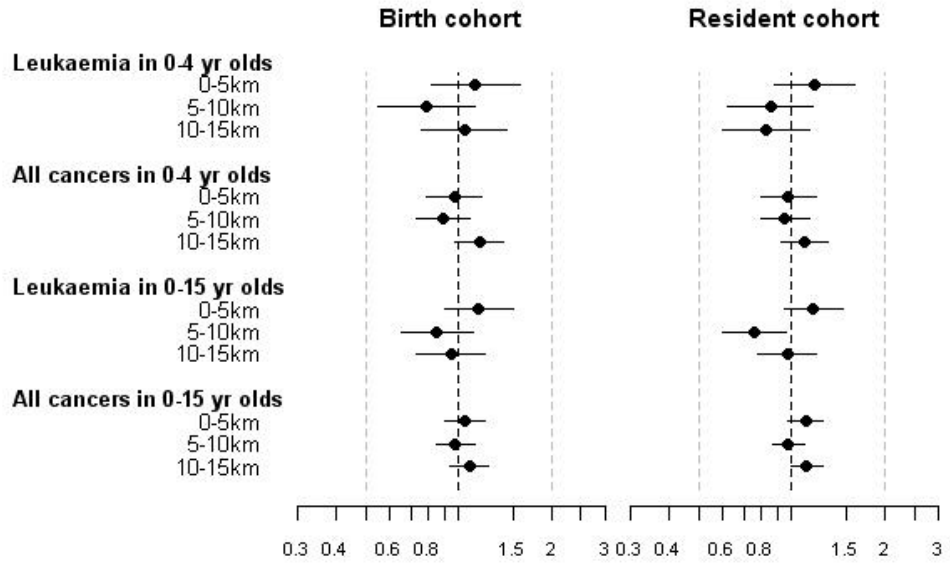


Figure E 8: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and artificial background radiation.



Adjusting for radiation from radio and TV transmitters

Figure E 9: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and radio and TV transmitters.

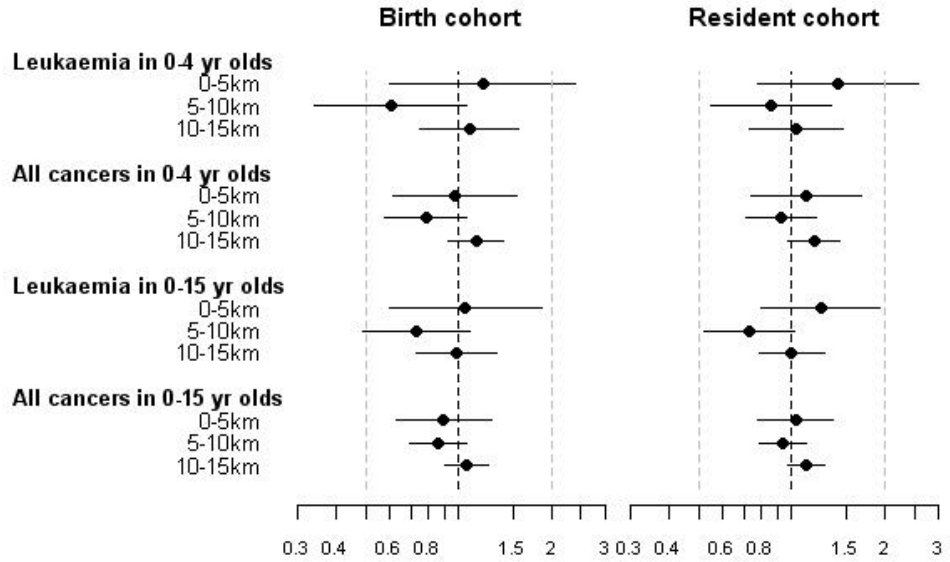
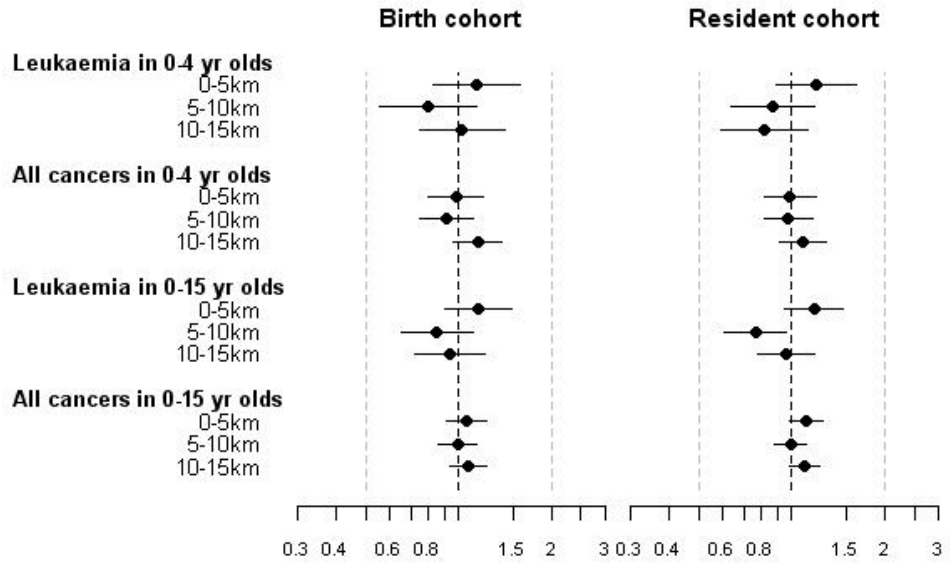


Figure E 10: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and radio and TV transmitters.



Adjusting for distance to multi-track railway lines

Figure E 11: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and multi-track railway lines.

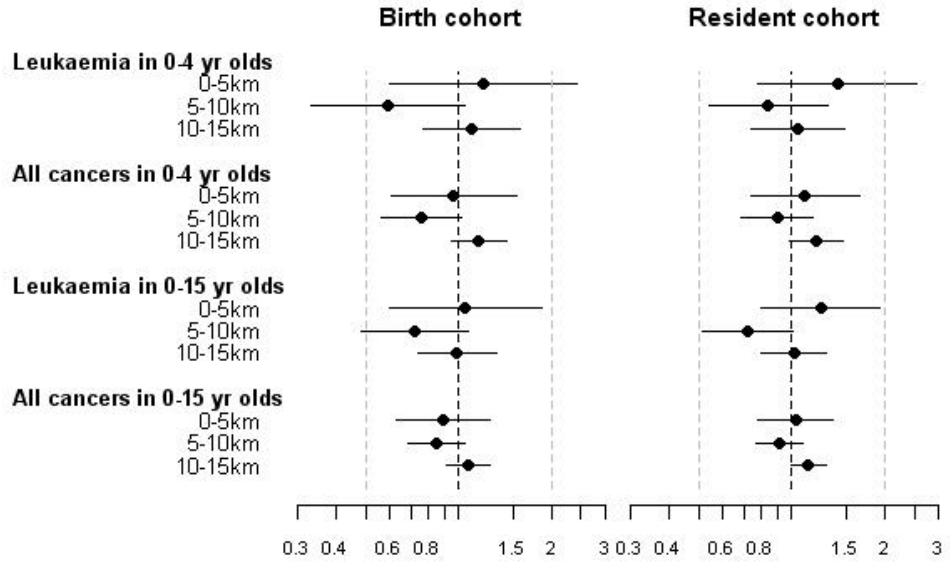
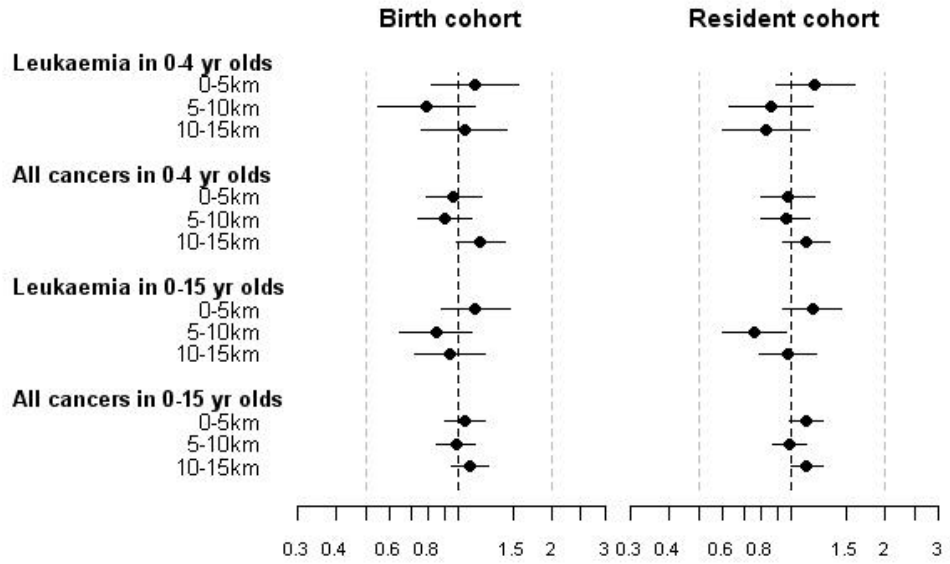


Figure E 12: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and multi-track railway lines.



Adjusting for distance to high voltage power lines (≥200kV)

Figure E 13: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and high voltage power lines.

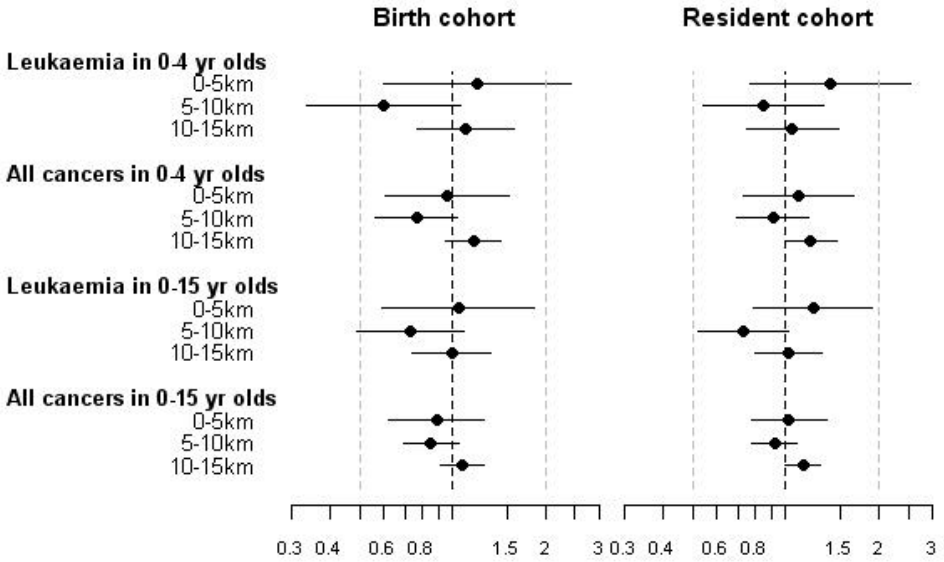
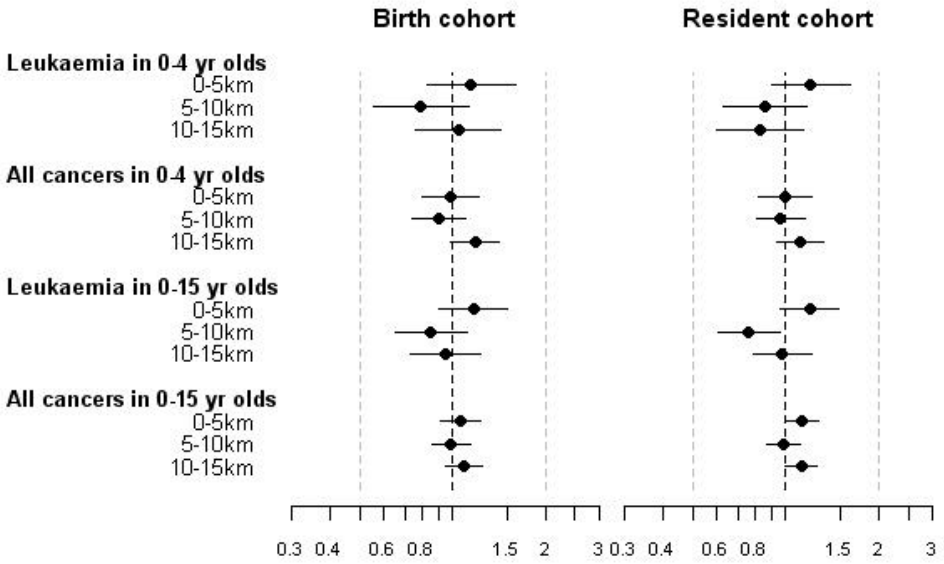


Figure E 14: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and high voltage power lines.



Adjusting for distance to major roads and highways

Figure E 15: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and major roads and highways.

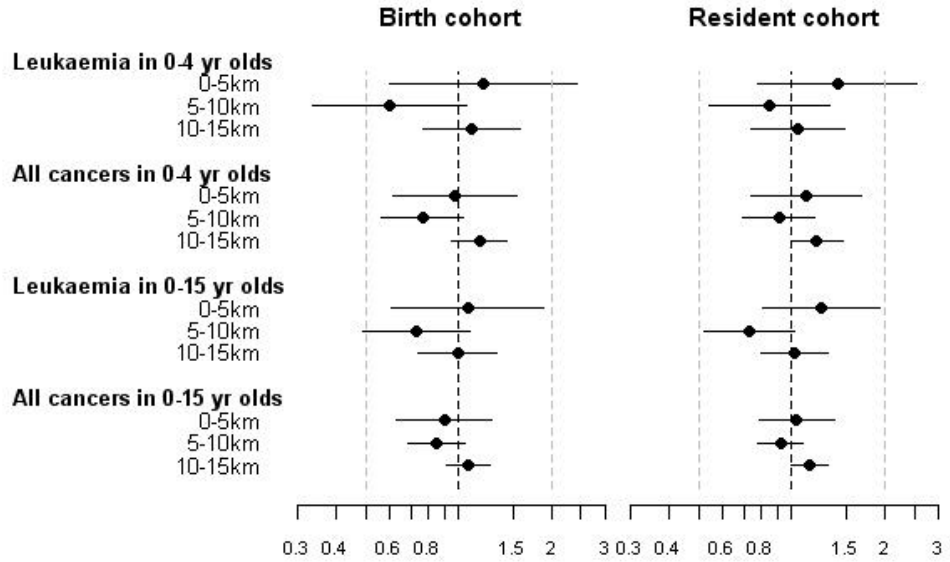
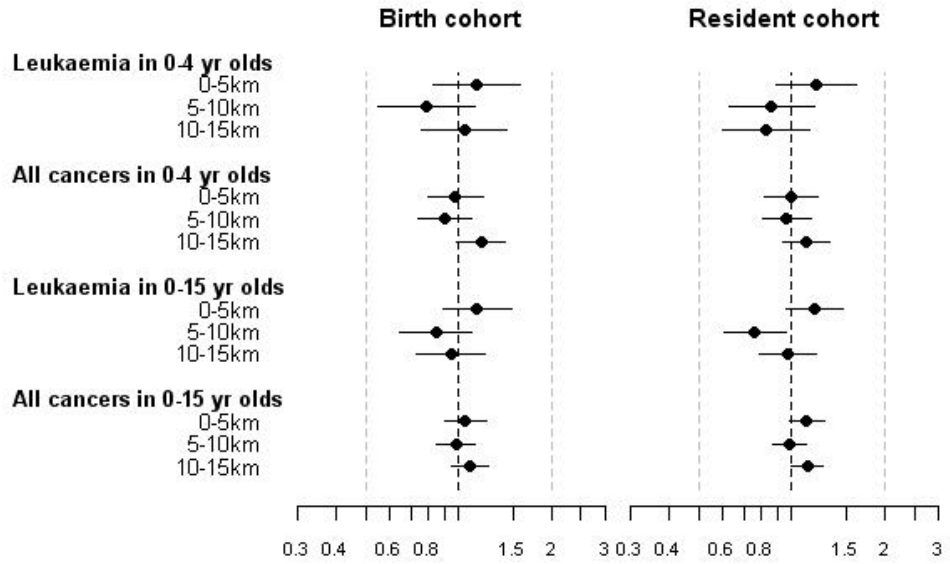


Figure E 16: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and major roads and highways.



Adjusting for distance to fruit tree cultivation land use plots

Figure E 17: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and fruit tree cultivation.

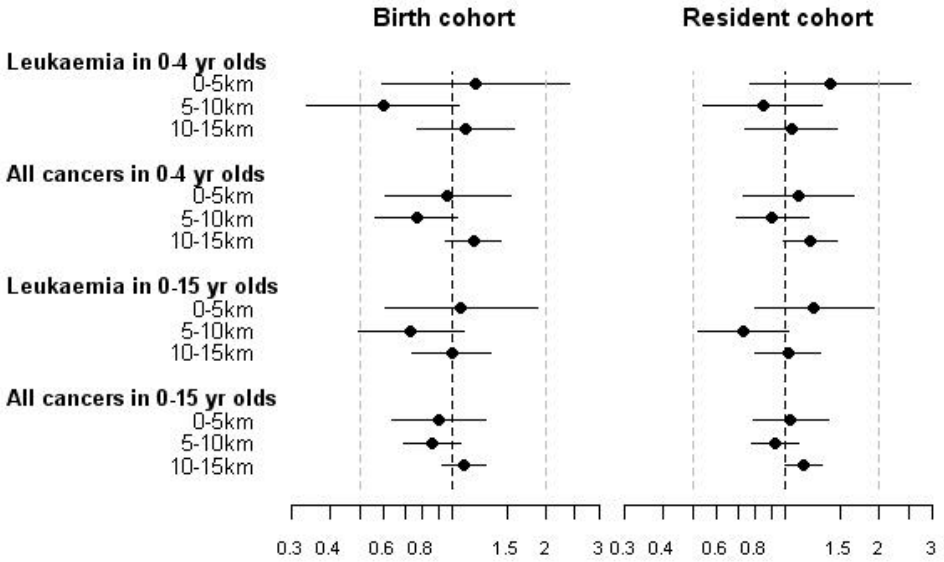
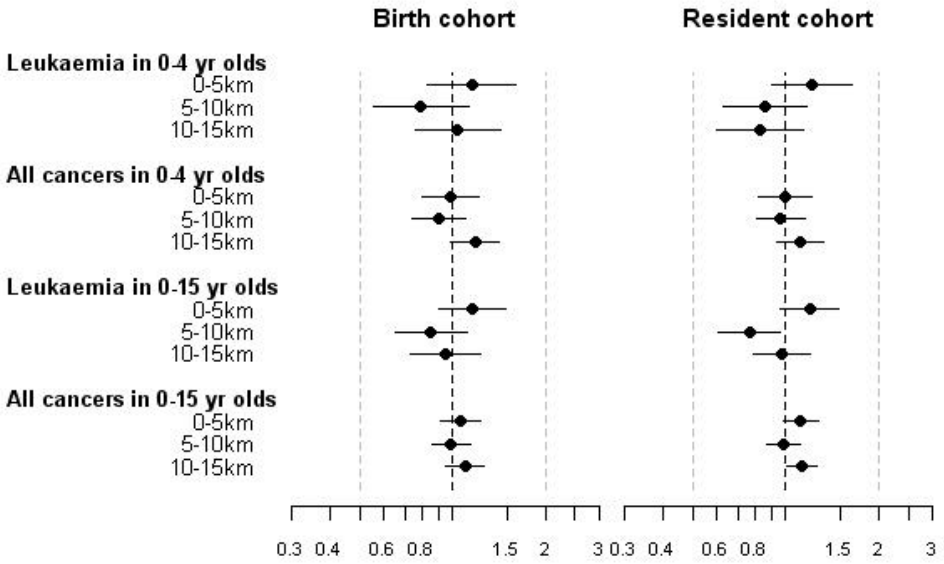


Figure E 18: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and fruit tree cultivation.



Adjusting for distance to grape vine cultivation land use plots

Figure E 19: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and grape vine cultivation.

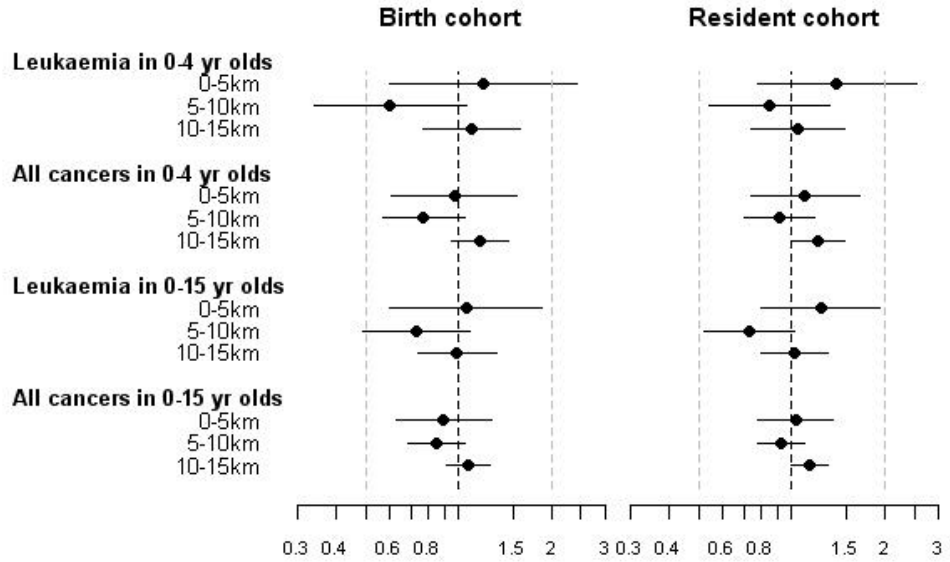
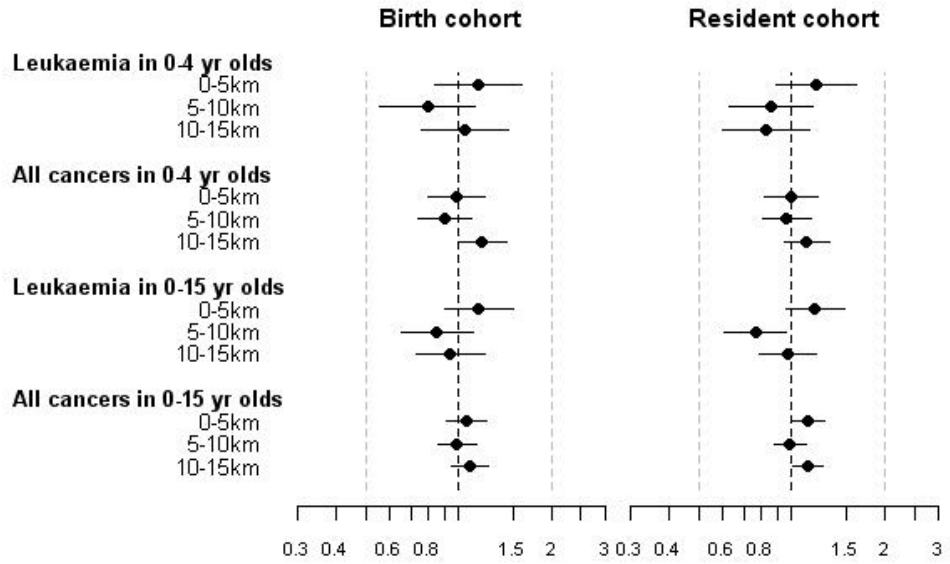


Figure E 20: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and grape vine cultivation.



Adjusting for distance to golf courses

Figure E 21: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and golf courses.

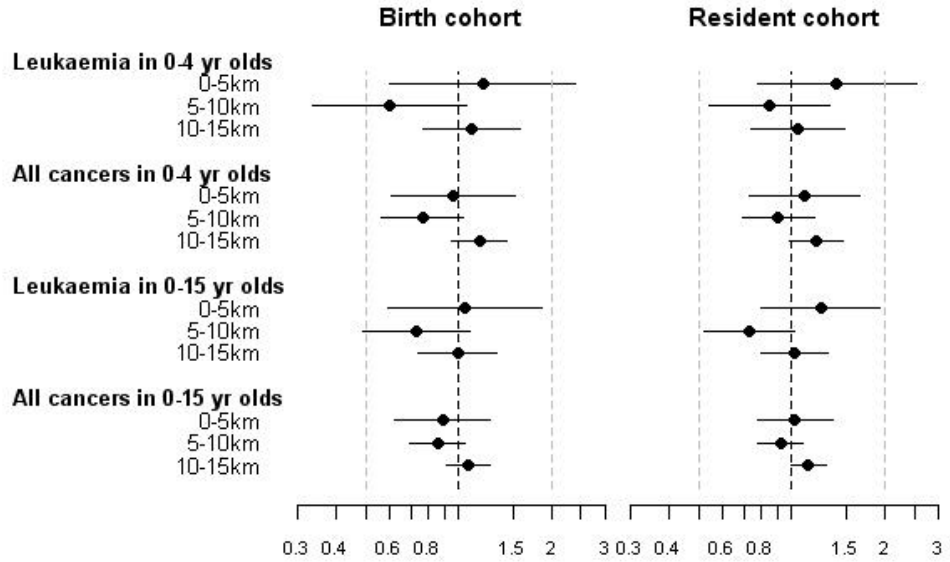
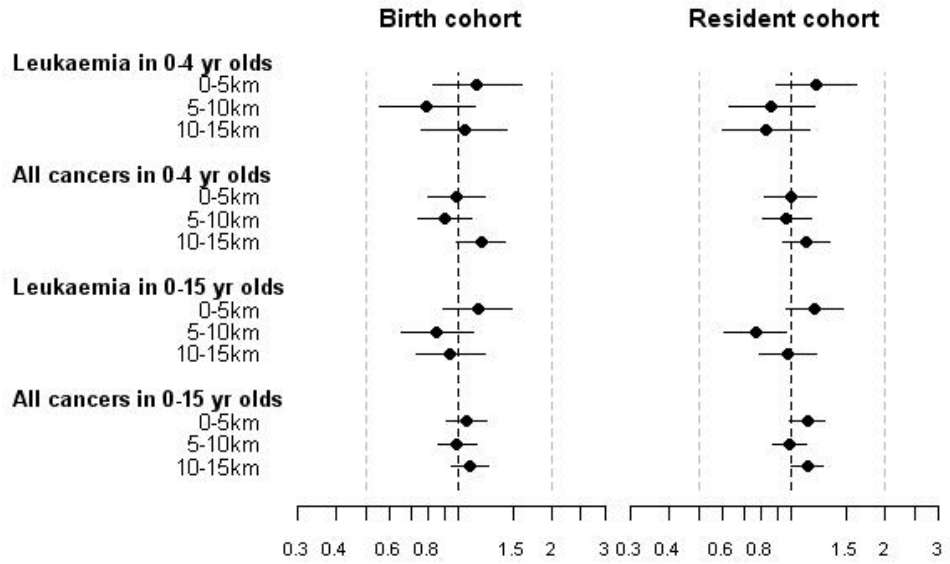


Figure E 22: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and golf courses.



Adjusting for distance to paediatric cancer centres

Figure E 23: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and proximity to paediatric cancer centres.

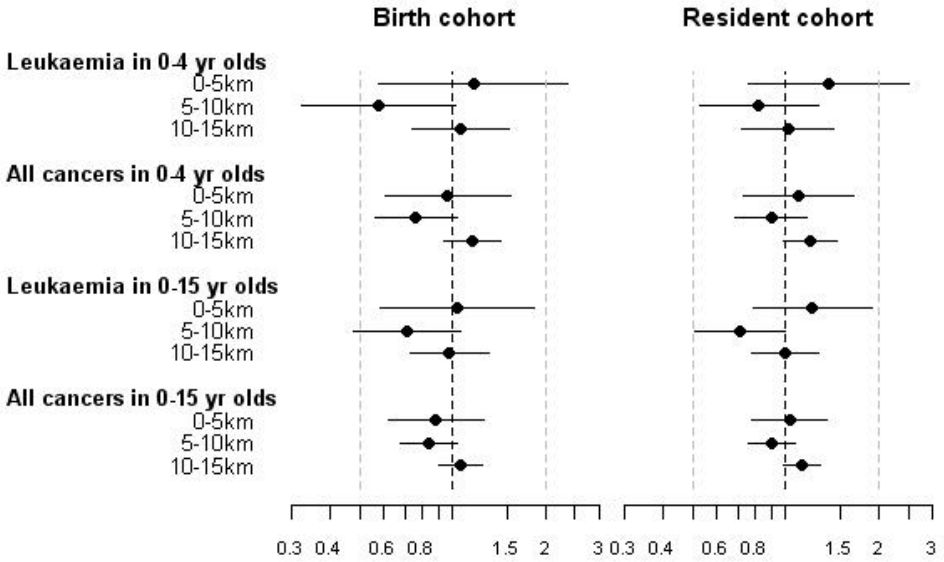
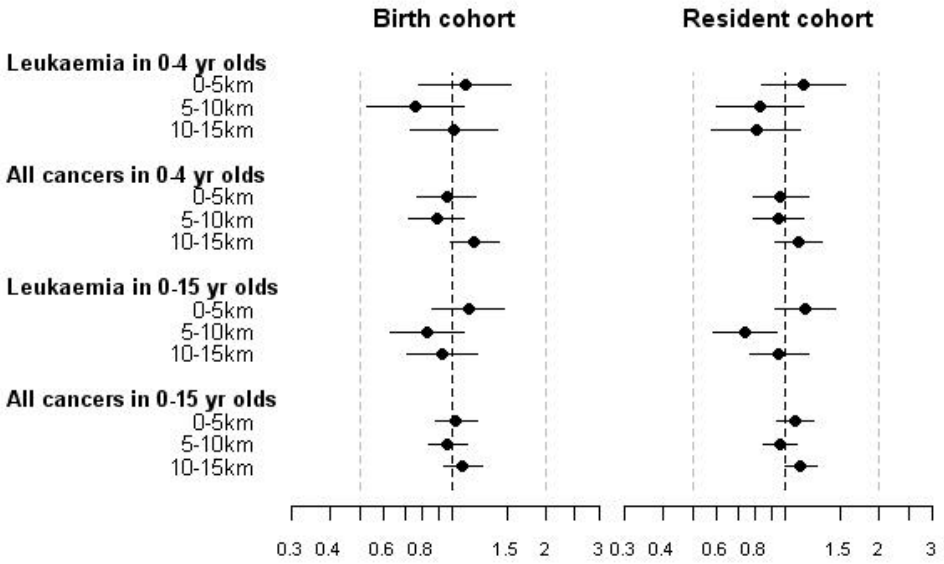


Figure E 24: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and proximity to paediatric cancer centres.



Adjusting for socioeconomic status (community based; quintiles)

Figure E 25: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and socioeconomic status.

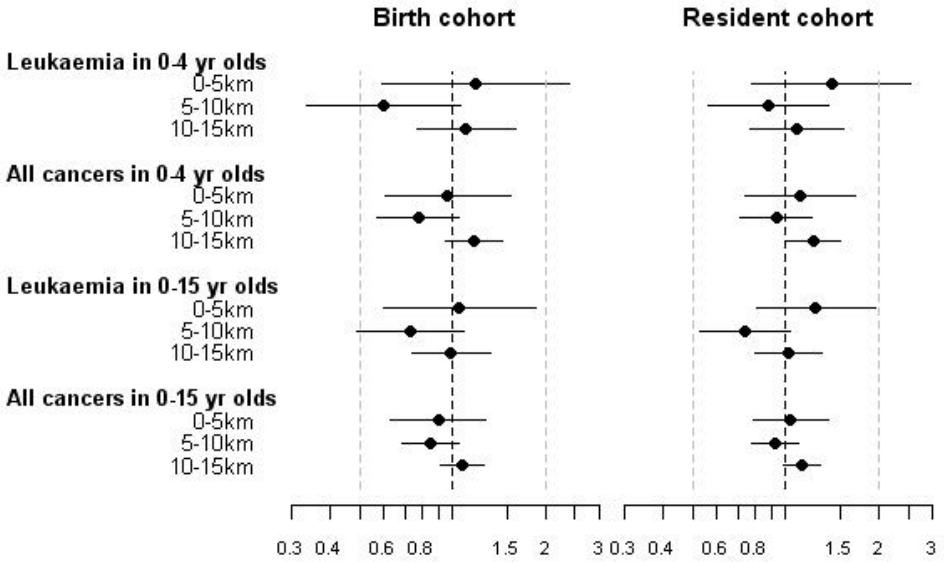
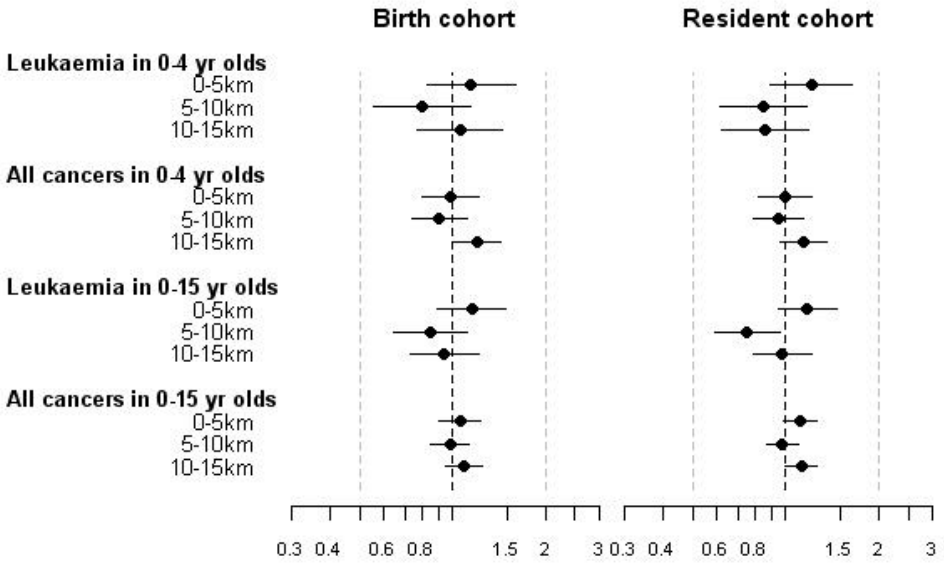


Figure E 26: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and socioeconomic status.



Adjusting for average number of children aged 0-15 years per household (community based; quintiles)

Figure E 27: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and average number of children aged 0-15 years per household.

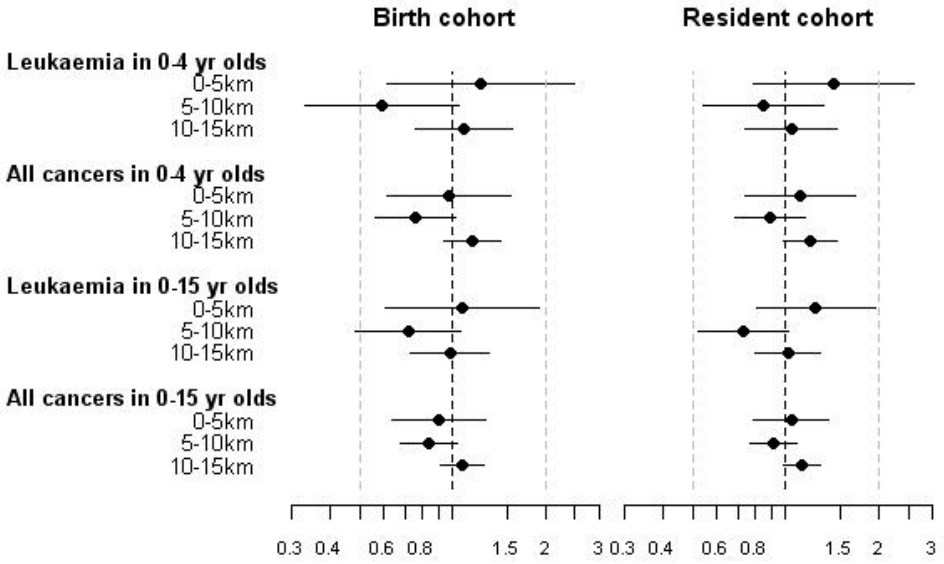
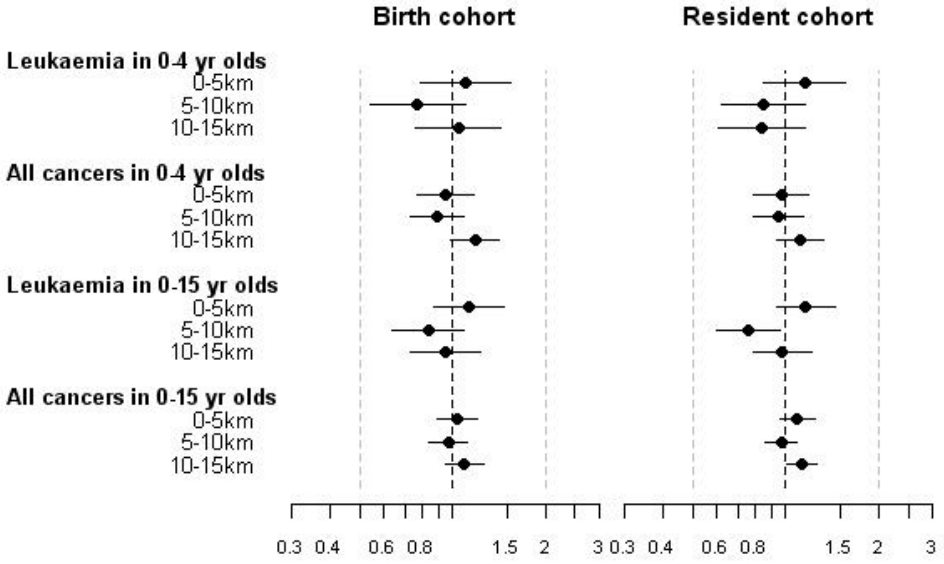


Figure E 28: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and average number of children aged 0-15 years per household.



Adjusting for degree of urbanization

Figure E 29: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year and degree of urbanisation.

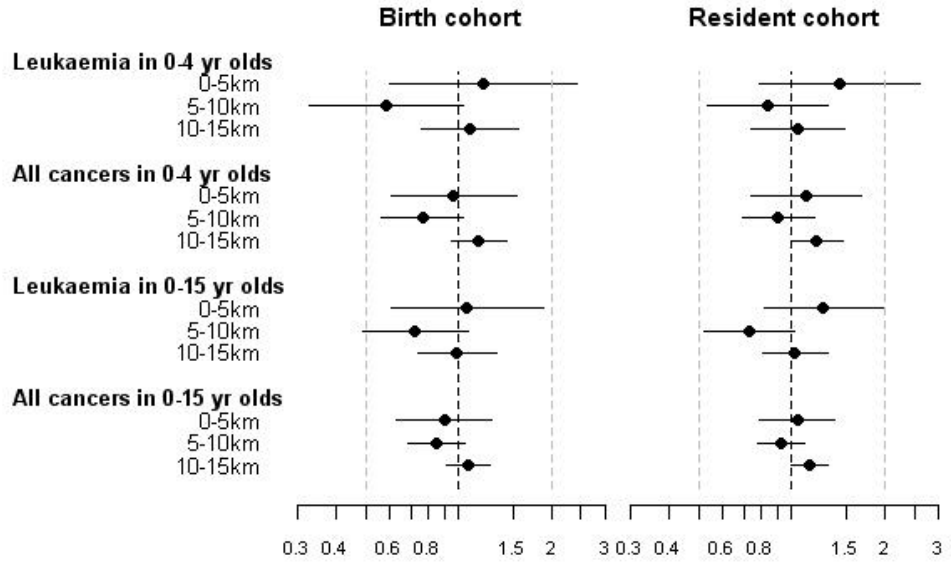
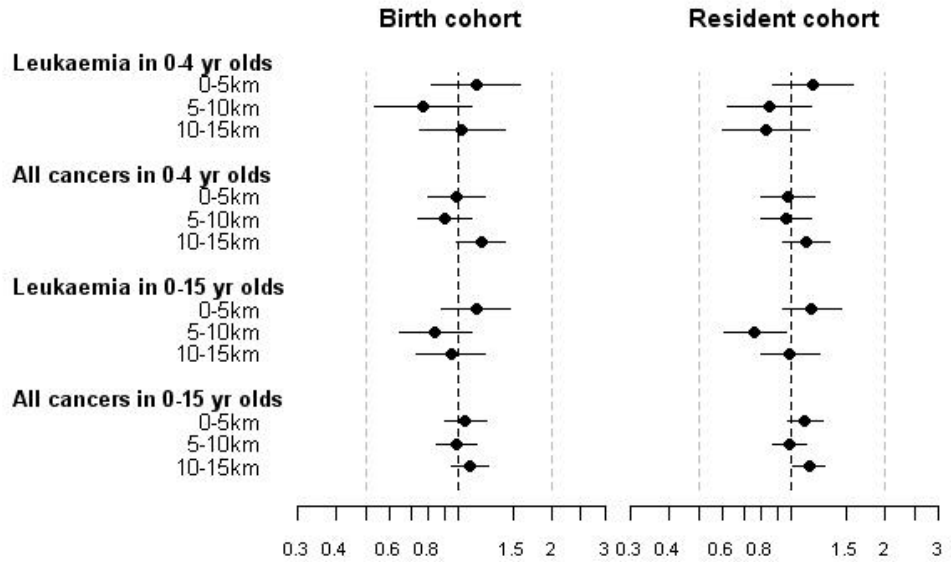


Figure E 30: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year and degree of urbanisation.



Sensitivity and additional analyses

1. Accounting for average wind directions

To account for average wind directions the main exposure was redefined as living within a zone around a NPP covering the area equivalent to a circle of 5km radius but extending radially from the NPP up to a distance proportional to the average duration of slow winds (<3m/s) in a given direction as measured at the NPP site (data source: Federal Office of Meteorology and Climatology (MeteoSwiss)). The figures below show the boundaries (black) of these zones around the 4 NPP sites (dot in centre) and in the 5km circular zone (blue) used in the main analysis. The x and y-axes point in eastward and northward respectively and distances are in metres from the NPP.

Figure E 31: Exposure regions around NPPs according to average wind directions.

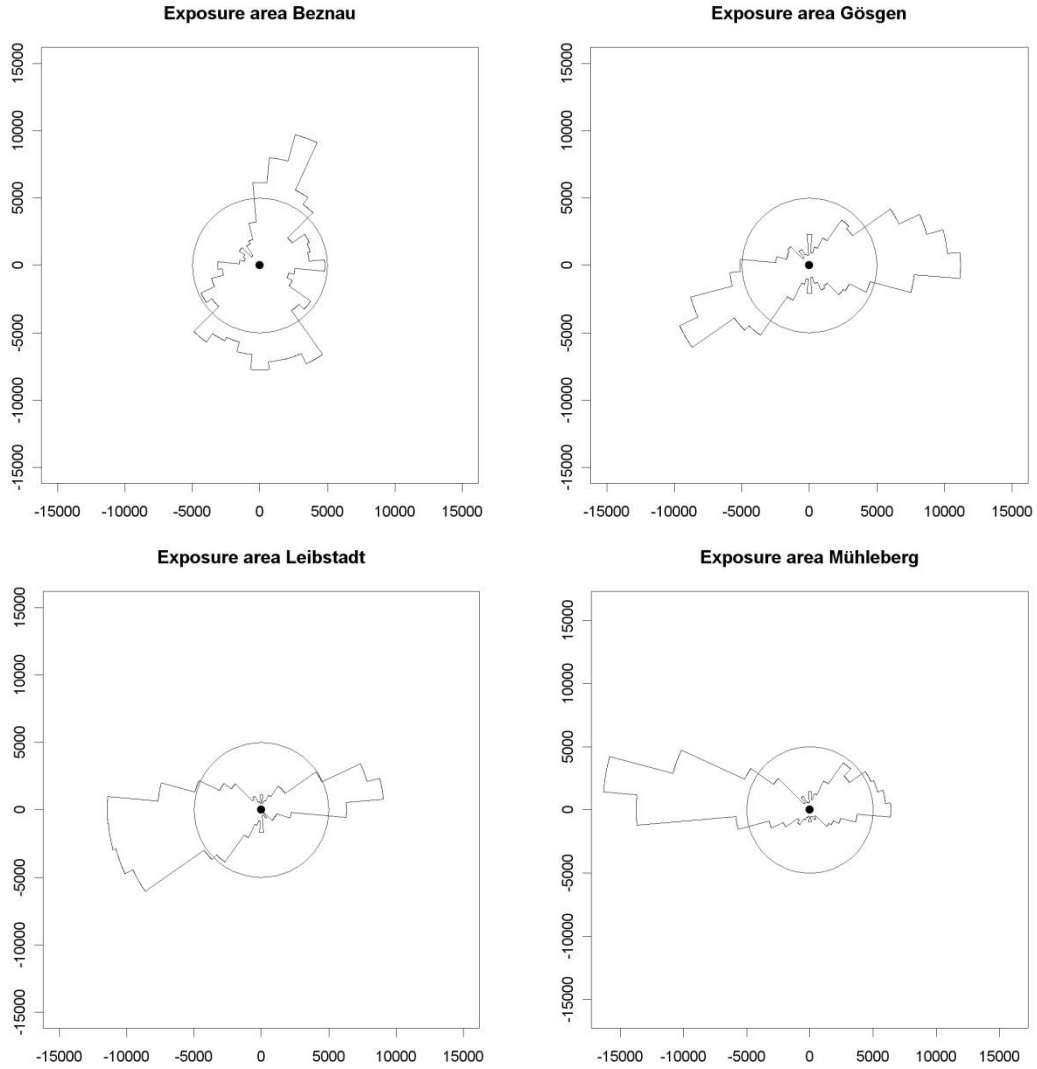
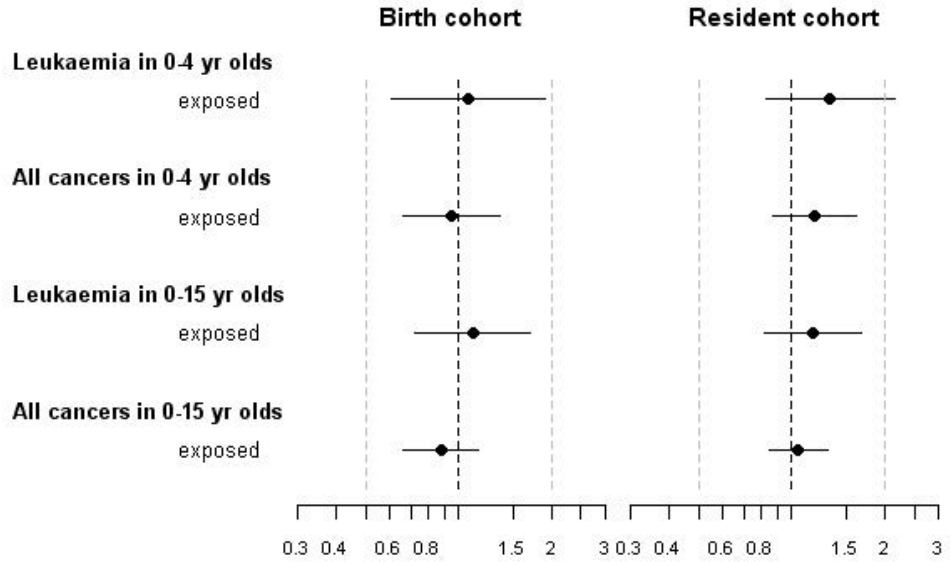
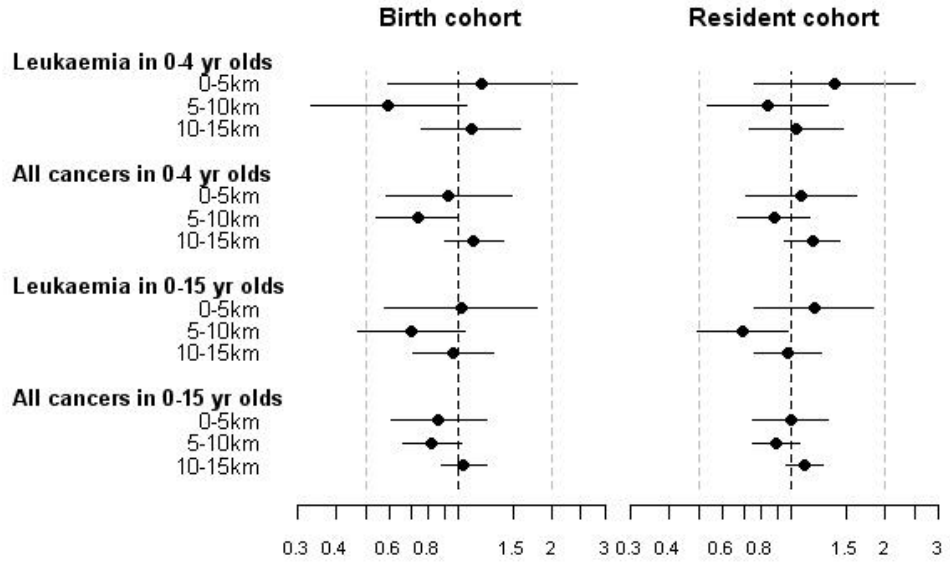


Figure E 32: Incidence rate ratios and 95% CIs comparing children living within the exposure zones around NPPs defined by average wind directions to those outside adjusted for sex, age, calendar year.



2. Including only children within the 50km zone of NPPs

Figure E 33: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year including only children residing within the 50km zone of a NPP.



3. Excluding calendar years 1985-90 and 2009

This analysis excludes calendar years 1985-90 and 2009 when registry of cancer diagnoses in the SCCR was less complete.

Figure E 34: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year excluding calendar years 1985-90 and 2009.

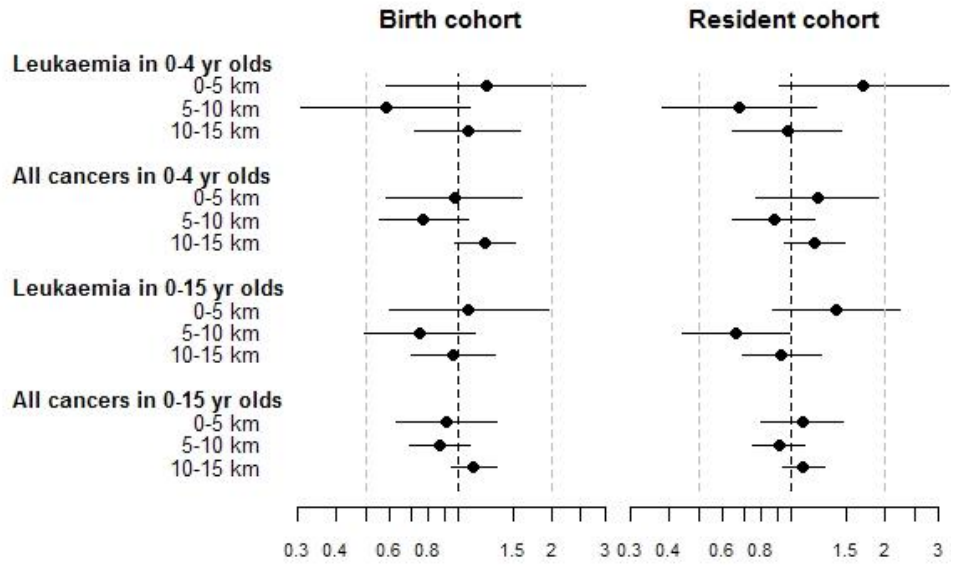
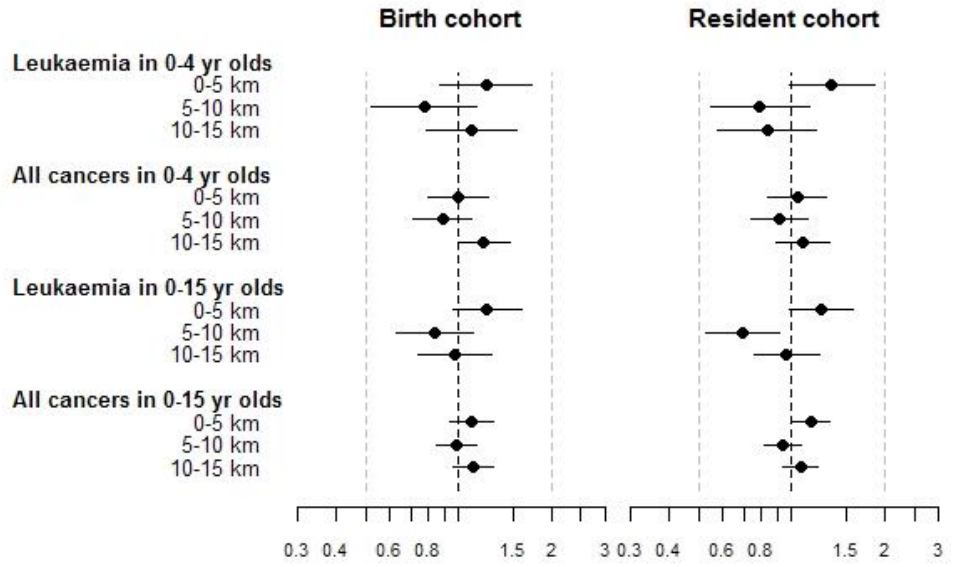


Figure E 35: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year excluding calendar years 1985-90 and 2009.



4. Including only children born in Switzerland ≥ 1985

Figure E 36: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year including only children born in Switzerland between 1985 and 2009.

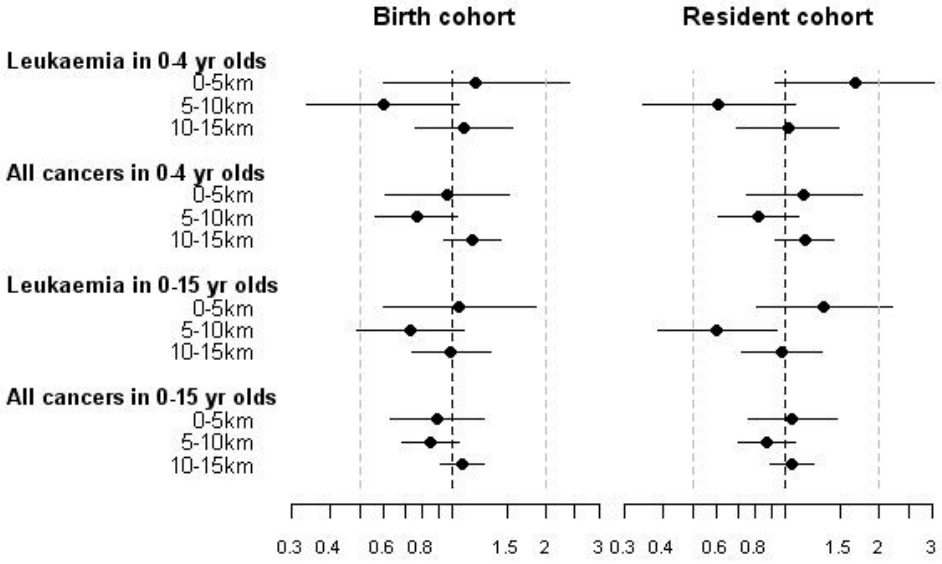
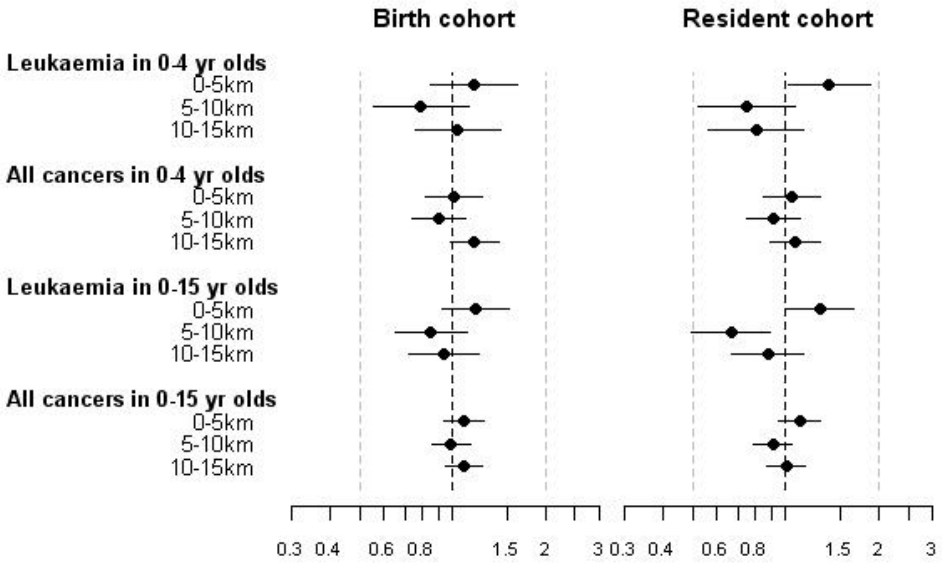


Figure E 37: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year including only children born in Switzerland between 1985 and 2009.



5. Alternative calculation of person years – cohort method

This analysis used the cohort method for inter-/extrapolation of person years instead of the age method used in the main analysis (see Webappendix 1).

Figure E 38: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year using the cohort method for calculating person years (details in webappendix 1).

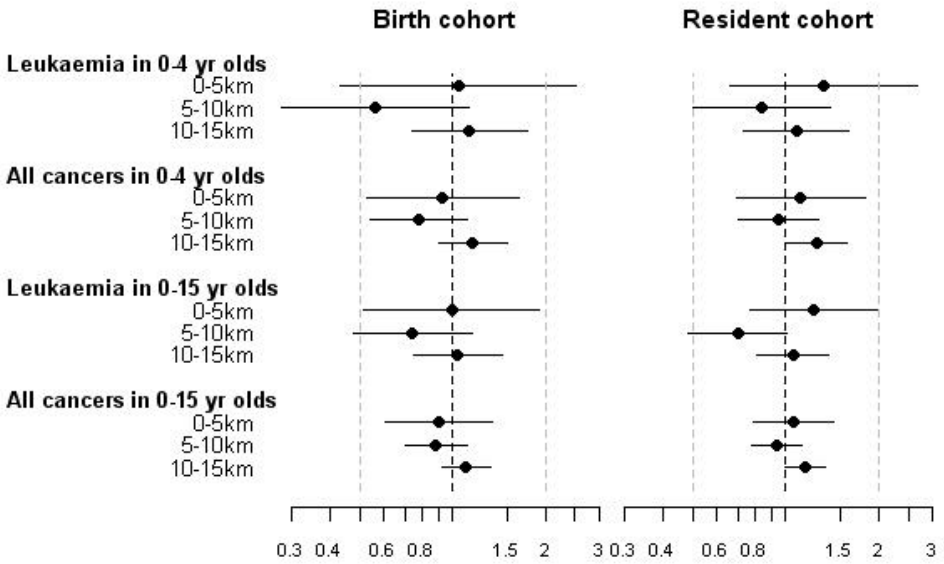
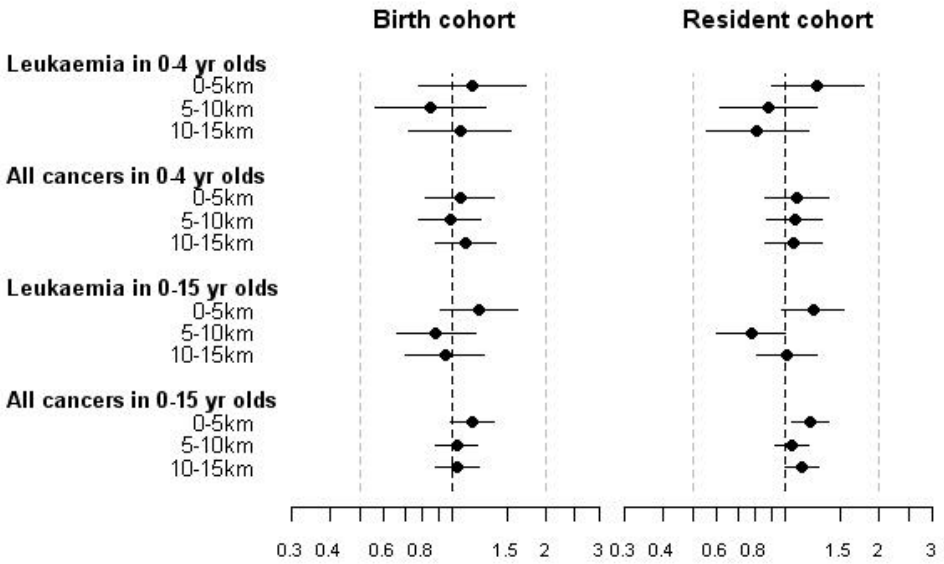


Figure E 39: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year using the cohort method for calculating person years (details in webappendix 1).



6. Excluding each of the three NPP regions from the analysis one at a time

In these analyses, the three NPP regions, Beznau and Leibstadt (counted as a single region), Gösgen, and Mühleberg were excluded one by one from the exposure definition, i.e. minimum distance was calculated only with respect the NPPs not excluded.

Figure E 40: Incidence rate ratios and 95% CIs by distance to any of the NPPs Mühleberg or Gösgen (excluding Beznau and Leibstadt) adjusted for sex, age, calendar year.

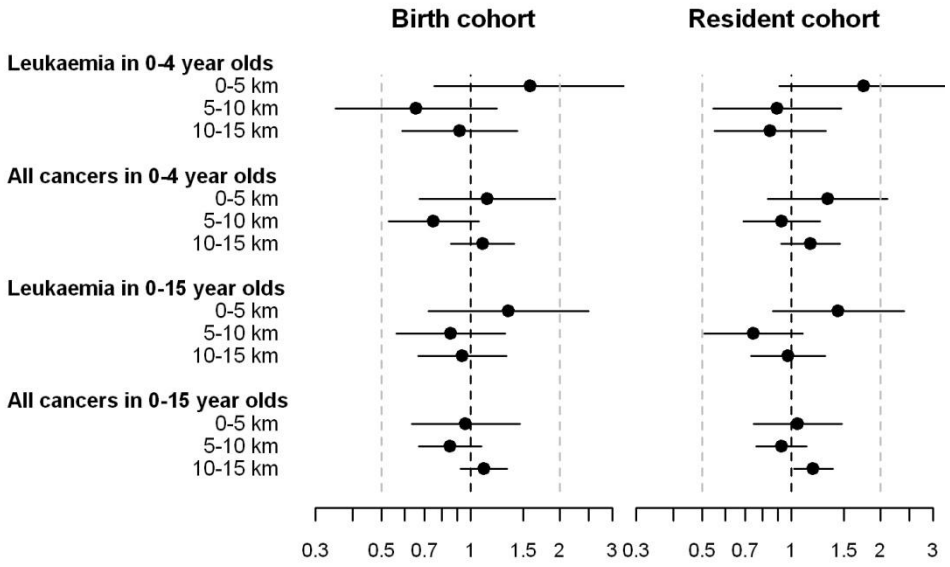


Figure E 41: Incidence rate ratios and 95% CIs by distance to any of the NPPs Mühleberg, Beznau or Leibstadt (excluding Gösgen) adjusted for sex, age, calendar year.

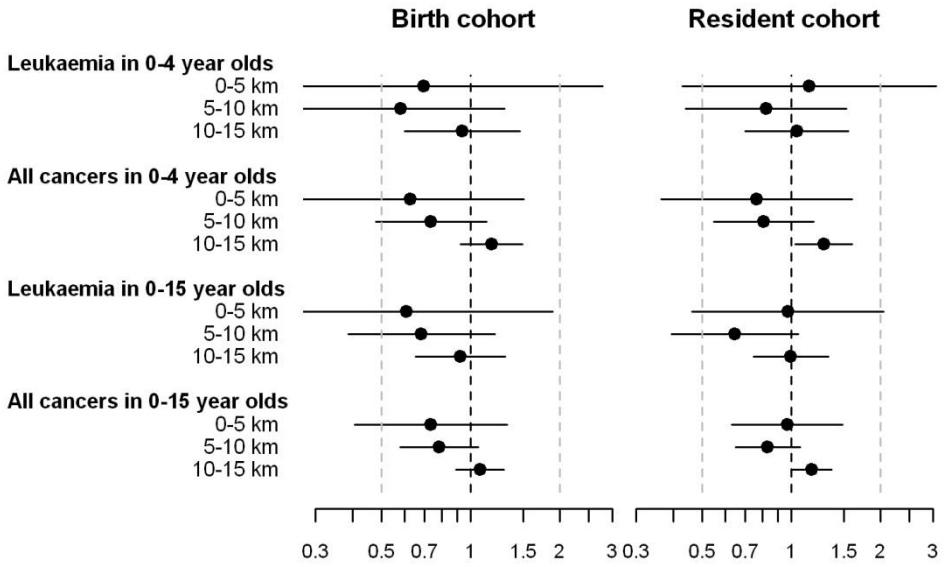
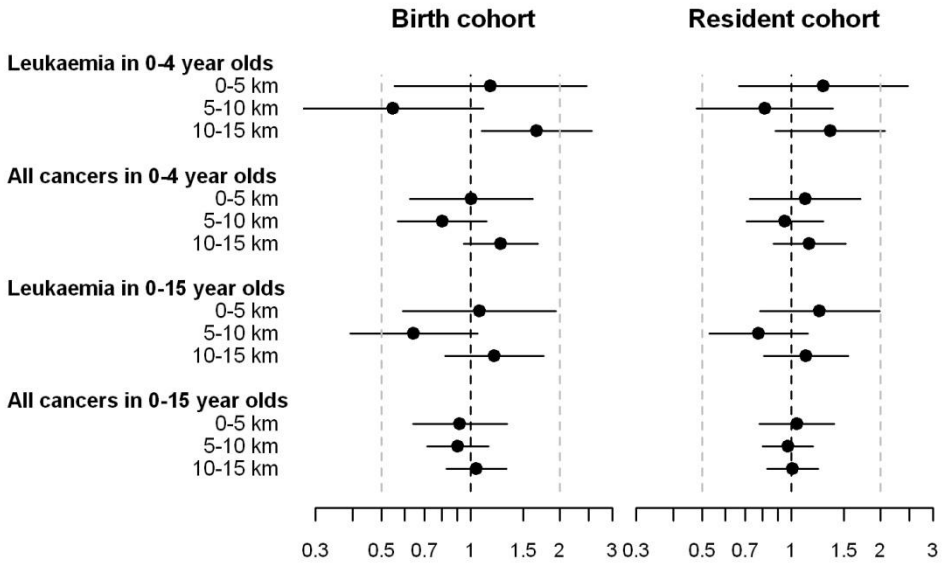


Figure E 42: Incidence rate ratios and 95% CIs by distance to any of the NPPs Gösgen, Beznau or Leibstadt (excluding Mühleberg) adjusted for sex, age, calendar year.



7. Stratification by calendar period:

Period 1985-94

Figure E 43: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year for the period 1985-1994.

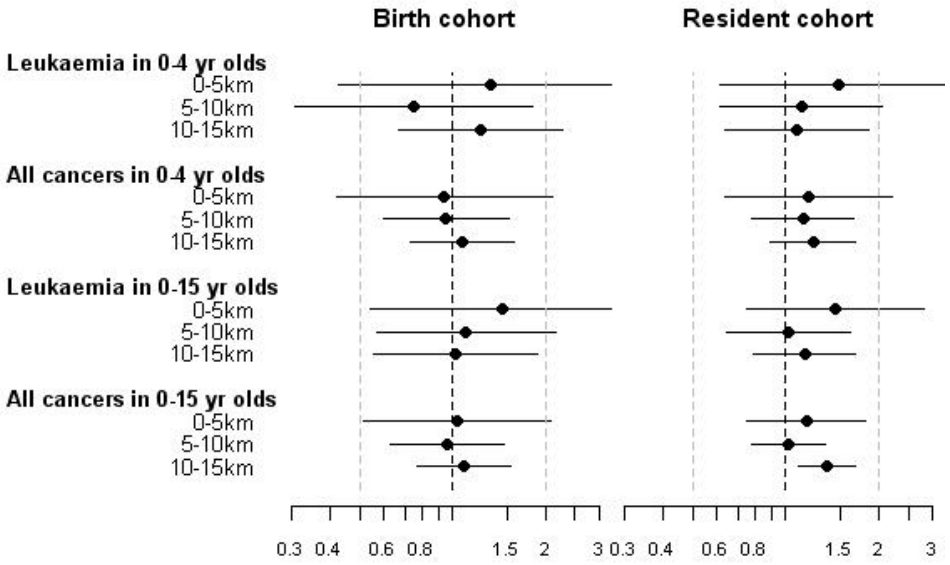
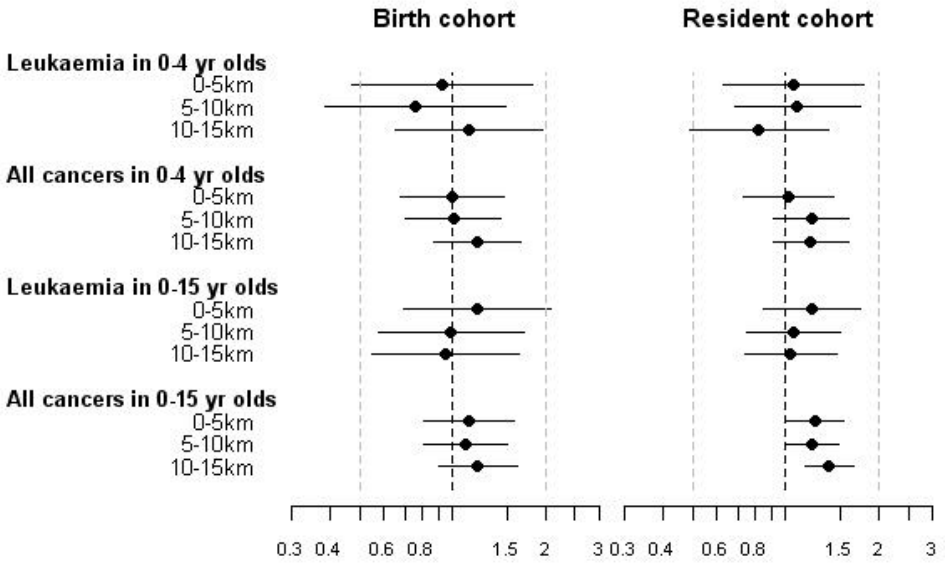


Figure E 44: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year for the period 1985-1994.



Period 1995-2009

Figure E 45: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year for the period 1995-2009.

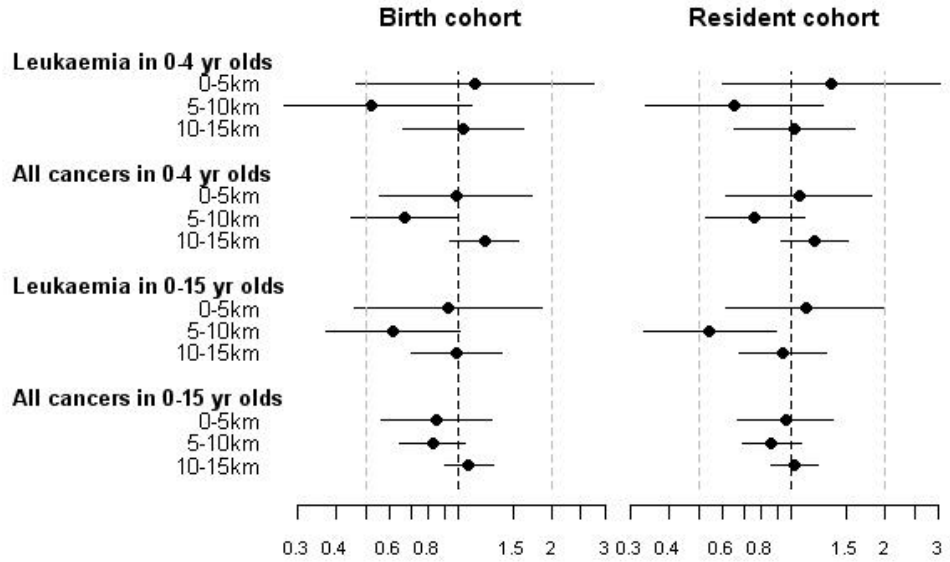
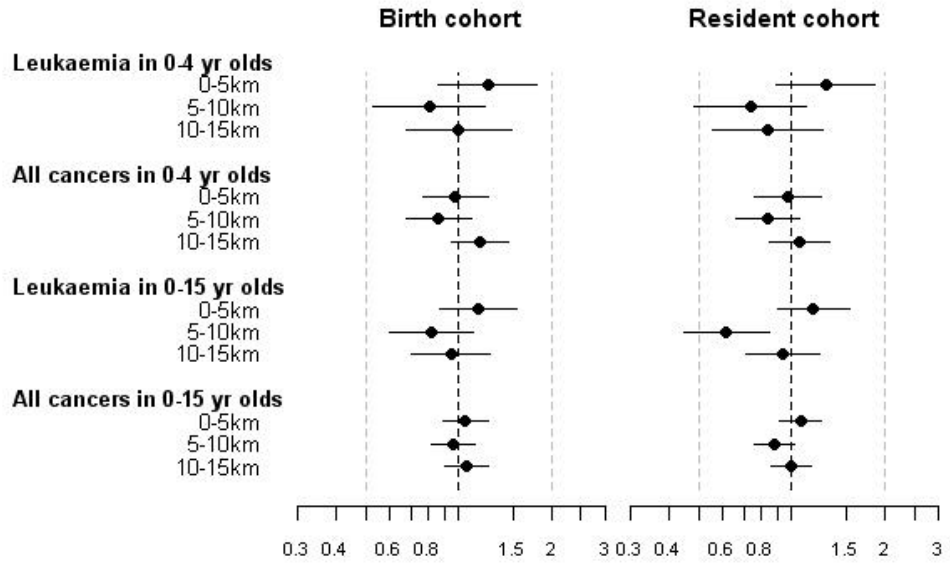


Figure E 46: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year for the period 1995-2009.



8. Including only children still living in their community of residence at birth

In this analysis we attempted to control for potentially differing cancer risks between children who moved and those who did not move since birth. The analysis included only cancer cases with fully traced address histories who continually lived at the same address between birth and diagnosis of cancer. Person years were computed using the cohort method (see webappendix1) including only children from the censuses reporting to have been living at the same address 5 years earlier (if ≥5 years old) and to have been resident of the same community at birth. The cohort method was used because the inclusion criterion of having remained in the same community is a condition placed on the cohort of children born in that community. For these analyses for the birth and resident cohorts should be equivalent as confirmed in the figures below (small numerical differences in the results do exist).

Figure E 47: Incidence rate ratios and 95% CIs by distance to NPPs adjusted for sex, age, calendar year in children still living in their community of residence at birth.

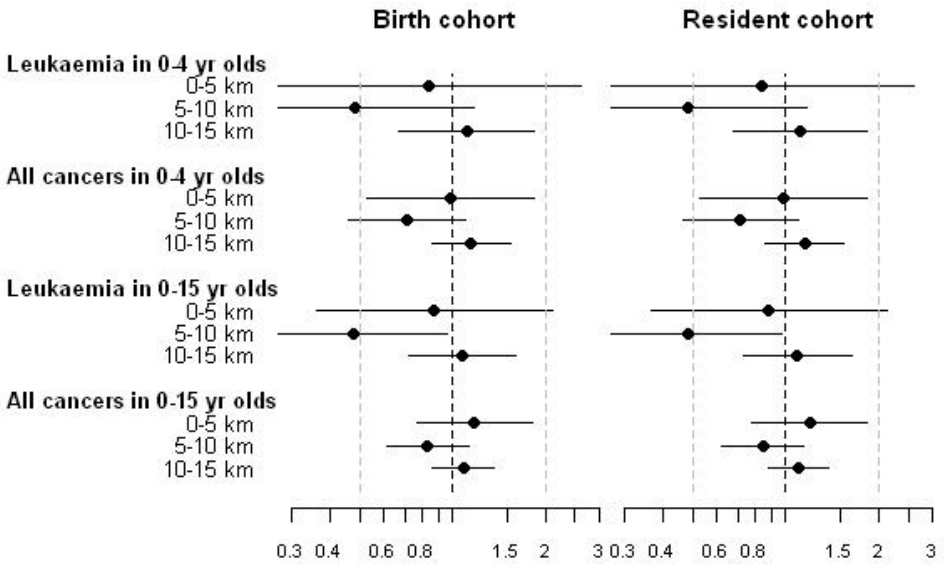
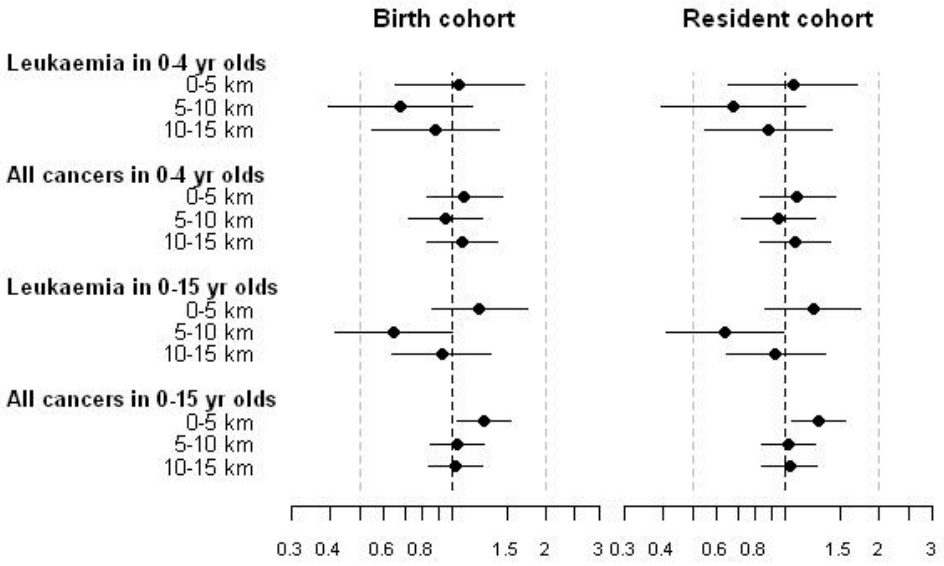
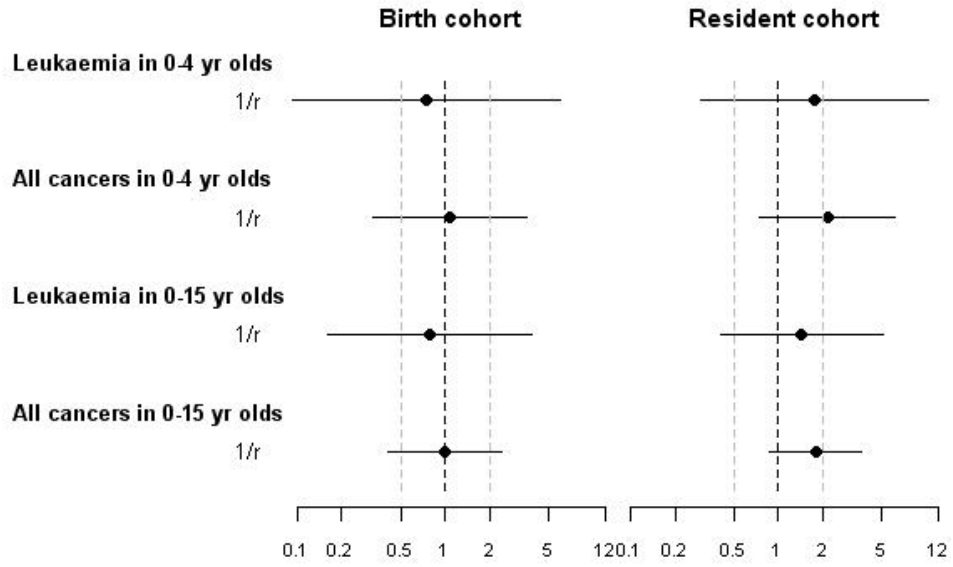


Figure E 48: Incidence rate ratios and 95% CIs by distance to any nuclear facility adjusted for sex, age, calendar year in children still living in their community of residence at birth.



9. Using 1/(distance in km) as a continuous exposure

Figure E 49: Incidence rate ratios and 95% CIs for a unit increase in a continuous exposure variable defined as 1/(distance to nearest NPP in km) adjusted for sex, age, calendar year.



10. Direct comparison of distance to NPPs between cases and population at risk

In this analysis we used crude data on distance to NPPs avoiding categorisation into distance categories and calculation of person years. Instead, we directly compared distance from place of residence to NPPs between cases and the population at risk. For cases, distances were computed using residential addresses at birth. These were compared to distances computed for residential addresses of children aged <1 year in the census years. The analysis is therefore not confounded by age. To avoid confounding by year of birth we only included children diagnosed with cancer who were born in the period from 2 years before until 2 years after the census year (5 years in total). Analyses were performed separately for the two census years 1990 and 2000. Because the main interest is in the left tail of the distribution, i.e. close to NPPs, we restricted analysis to the 50km zone around NPPs. We used two-sample t-tests and the Mann–Whitney U test and all tests are two-sided. We also show density histograms of distance to nuclear facilities separately for cases and the population at risk and in overlap highlighting differences between the distributions.

Table E 2: Testing for differences in the distribution of distances to NPPs between children diagnosed with cancer and children at risk (only distances <50km considered).

Census	N*	Distance from NPP		Diagnoses	N†	Distance from NPP		P-values	
		mean ±SD	IQR			mean ±SD	IQR	t-test	MW test
1990	45416	27.62 ±11.85	18.53-36.81	Leukaemia in 0-4 yr olds	85	28.70 ±11.53	19.52-37.40	0.403	0.381
				All cancers in 0-4 yr olds	229	28.42 ±11.18	19.52-36.87	0.307	0.351
				Leukaemia in 0-15 yr olds	159	28.34 ±11.51	19.08-36.83	0.446	0.404
				All cancers in 0-15 yr olds	502	28.34 ±11.65	19.08-37.12	0.177	0.146
2000	41498	28.24 ±11.52	19.75-36.84	Leukaemia in 0-4 yr olds	73	27.22 ±10.46	21.46-33.79	0.452	0.398
				All cancers in 0-4 yr olds	223	26.17 ±11.09	17.91-34.98	0.007	0.008
				Leukaemia in 0-15 yr olds	115	28.13 ±10.89	21.46-36.21	0.924	0.847
				All cancers in 0-15 yr olds	333	27.14 ±11.08	19.75-35.89	0.084	0.066

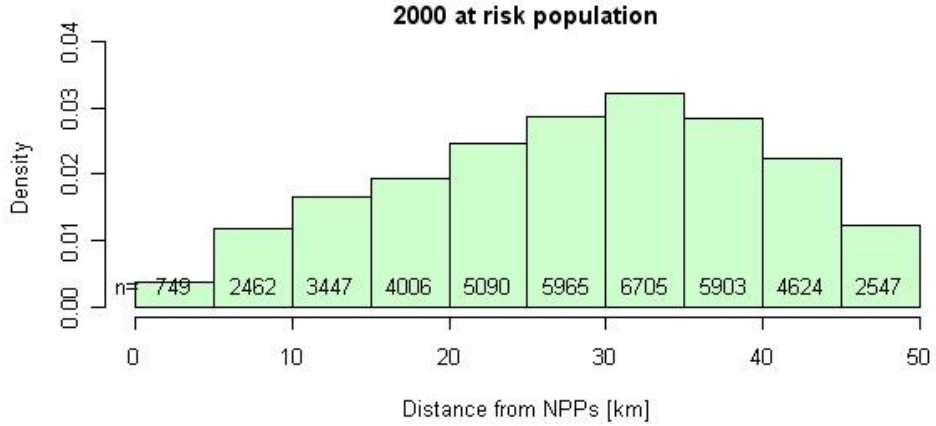
Abbreviations: SD standard deviation, IQR inter-quartile range, MW Mann-Whitney U test

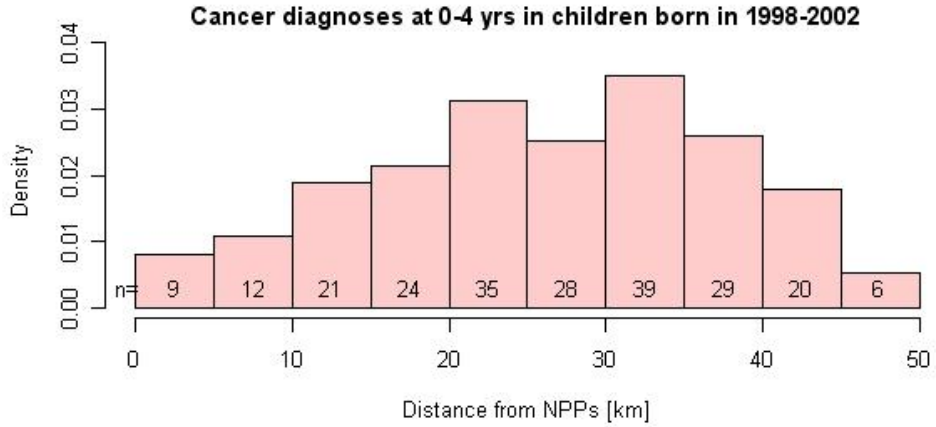
* All children in census aged <1 year

† Children diagnosed with cancer who were born in a 5 year period around the census years (census year ±2 years)

Interpretation: There is little evidence for a difference in the distribution of distances to NPPs between cases and the population at risk except for children diagnosed with any cancer at 0-4 years of age and possibly up to 15 years who were born around the 2000 census. However a visual comparison of these distributions (Figures E50-51) shows that an excess of cases is not restricted to the distance categories immediately around the NPPs but is also seen at intermediate distances and there are no indications of a trend in excess of cases with decreasing distance to NPPs.

Figure E 50: – All cancer diagnoses in 0-4 year old children and population at risk in 2000.





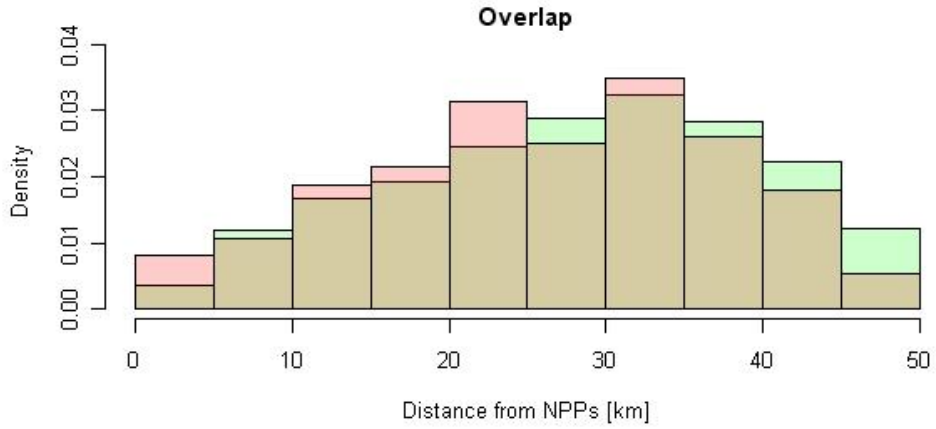
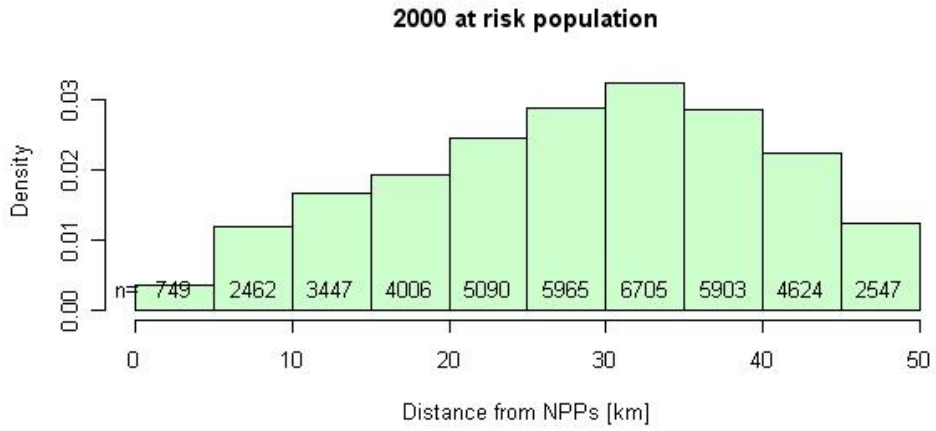
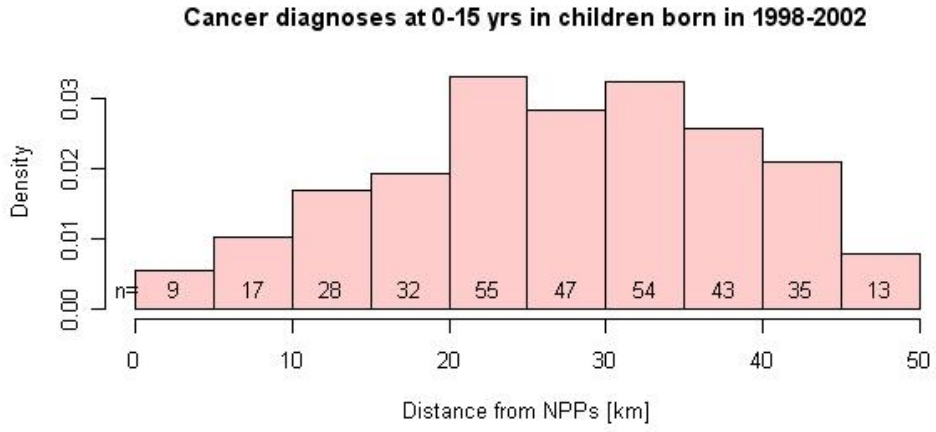
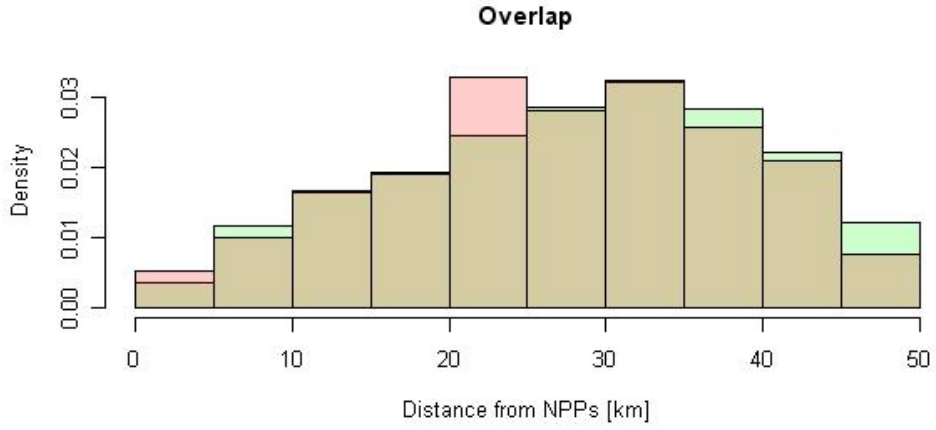


Figure E 51: – All cancer diagnoses in 0-15 year old children and population at risk in 2000.







11. Summary of sensitivity analyses

Figure 5 in the main article and Figure E52 below summarise results of sensitivity analyses for the birth and resident cohort respectively.

Figure E 52: Comparison of results of main and sensitivity analyses for the resident cohort. Incidence rate ratios adjusted for sex, age and year at diagnosis and 95%CIs comparing children living <5km with children living >15km from a NPP. Results are adjusted for sex, age and year at diagnosis. Analyses numbered as in Box 1 of the main article.