

Childhood cancers, birthplaces, incinerators and landfill sites

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Background In all, 70 municipal incinerators, 307 hospital incinerators and 460 toxic-waste landfill sites in Great Britain were examined for evidence of effluents causing childhood cancers. Municipal incinerators had previously shown significant excesses of adult cancers within 7.5 and 3.0 km. The relative risks for adults had been marginal and an analysis of childhood cancers seemed to offer a more sensitive approach.

Methods A newly developed technique of analysis compares distances from suspect sources to the birth addresses and to the death addresses of cancer-children who had moved house. A localized hazard, effective at only one of these times, must be preferentially associated with the corresponding address. This creates an asymmetry of migrations towards or away from age-restricted effective sources.

Results The child-cancer/leukaemia data showed no systematic migration-asymmetries around toxic-waste landfill sites; but showed highly significant excesses of migrations away from birthplaces close to municipal incinerators. Relative risks within 5.0 km of these sites were about 2:1. Hospital incinerators gave analogous results. The ratios greatly exceed findings around 'non-combustion' urban sites.

Conclusions Because of their locations, the specific effects of the municipal incinerators could not be separated clearly from those of adjacent industrial sources of combustion-effluents. Both were probably carcinogenic. Landfill waste sites showed no such effect.

Keywords Childhood, birthplace, cancer, leukaemia, incinerators, landfill, toxic-waste

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Elliott *et al*. demonstrated a statistically significant excess of cancers within 3.0 km and within 7.5 km of 72 municipal solid-waste incinerators in England, Wales and Scotland in the period 1974–1987.[1] This was based upon approximately 348 000 cancer registrations at all ages, inside 7.5 km. The proportional excesses were greater at the shorter of the two ranges tested. Lung and liver cancers showed a substantial relative excess.

Despite the presence of known carcinogens in incinerator effluents, a causal interpretation was not thought justified. This was mainly because the relative risks were small, around 1.04 overall; and because, as the authors also noted, long exposure-to-effect intervals meant that many subjects must have lived elsewhere at the times of relevant exposures. This would have weakened a real proximity effect rather than created a false one, but the investigators thought that their findings were probably due to geographical confounding between incinerator sites and other hazards. These hazards were thought likely to be social.

Similar problems of interpretation were also encountered in geographical studies of childhood cancer deaths in Great Britain between 1953 and 1980.[2–5] There was evidence of short and medium range spatial clustering and there were statistically significant excesses of cancer births and cancer deaths near industrial plants using either solvents or large-scale high-temperature combustion processes.[6] Municipal incinerators, for lack of site-data, were not examined. The relative risks were moderate, around 1.2, and the possible effects of socio-geographic confounding could not certainly be excluded.

However, these childhood findings were based upon two independent modes of analysis which, in the event, returned concordant results. The first method related numbers of cases to indices of child populations living within short distances of putative hazards. For lack of exact demographic data these indices were based upon numbers of postcodes within defined radii. The second method was devised in order to counter the implicit uncertainties of this first approach and it utilized patterns of migration among those children who had moved house between birth and death.[7] It invoked the premise that a localized exposure to a cancer-initiating hazard, operating at only one of these times, would result in different degrees of geographical proximity at birth and at death. For example, a toxic source operating shortly before or after birth, would exhibit closer geographical associations with birth addresses than with later death addresses. Given some minimum migration distance, it

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would not be possible for both addresses to adjoin the same hazard site. Specifically, the observed migrations would then more often be directed away from genuine birth-time hazards than towards them. If there were socio-geographic artefacts here then they probably differed from those to which the earlier method was liable. The new method confirmed and amplified almost all of the earlier findings, and it showed others in addition.

The migration-based method was more sensitive than the older PC-based approach for several reasons. First, having sought out the hazards surrounding each address, it utilized only the closest of these sources, thus eliminating less informative geographical associations. Next, the use of 'within-child' contrasts (between birth- and death-distances) eliminated non-informative 'between-child' variability. Finally, the migration method allowed prior selection of the most informative migration patterns for testing specific hazard types. For example, rooftop-level emissions from small factories should result in steep radial exposure gradients over short distances, which should then be detectable among those migrations with one address very close to a source; while discharges from tall stacks produce shallow and sometimes complex exposure gradients over longer ranges, and justify less restricted distance criteria. The method is essentially a formalization of a classical epidemiological approach.

The migration method, and the availability of extensive appropriately dated childhood cancer data, raised the possibility of re-analysing the incinerator data assembled by Elliott *et al*. Latent intervals for childhood cancers are necessarily short, and children's sensitivities to environmental hazards are probably greater than for adults, thus mitigating the main problems encountered in the 'all-ages' analysis. If the data could be found, then other waste disposal sites might also be examined and compared. These were the primary objectives of the present investigation.

Materials and Methods

The basic datasets used in this investigation, and details of the analytical technique, are all described elsewhere.[1]

The case material[2–7] was extracted from a file of all 22 458 cancer deaths occurring before the 16th birthday in Great Britain between 1953 and 1980. The file was originally assembled as part of a case-control study of the effects of prenatal radiation exposure but the controls were matched geographically with the cases and so were not suitable for the present investigation. For present purposes, Orkney and Shetland were excluded. Each tumour was classified to one of 11 groups; lymphatic, myeloid, monocytic and unclassified leukaemias: lymphomas, nephroblastoma, CNS-tumours, neuroblastoma, bone-cancers, other solid cancers, and fatal benign tumours.

Home addresses at death were recorded, and where parents were subsequently interviewed, the birth address was also obtained. Postcodes were identified and their map references were extracted from the Central Postcode Directory. In 9224 cases (41.1%) the child was known to have moved at least 0.1 km between birth and death; this group providing the basis for the migration studies. Another 9328 children (41.5%) had not moved, and we had no information on the previous movements of the remaining 3906 (17.4%). The exact dates of removals and of diagnoses were not uniformly recorded.

For 4385 of the 9224 migrating cancers, both addresses were precisely identified and the postcode map references were then generally accurate to within about 0.1 km. For most of the remainder the least precise address (almost always the birth address) was probably accurate to within about 1.0 km; although some may have been less so because of non-availabilities of street maps for many rural areas or for demolished zones and streets in some urban ones. The less precise map references might at first seem adequate for the examination of incinerators, which are designed specifically for a diffuse dispersal of their effluents, but some of the uncertain birth addresses had been allocated to city- or town-centre postcodes (e.g. xnn 1AA). Incinerators near urban centres could then become linked with these centripetally biased birth addresses, creating false apparent outward migrations. The present study is therefore based chiefly upon the more accurately identified locations. Analyses based also upon the less accurate map references were nevertheless conducted in order to exclude any selective associations between technical precision and proximities to potential hazards.

The sites of 72 municipal waste incinerators were kindly supplied by the Small Area Health Statistics Unit following publication of their own investigation.[1] These records contained both the map references and the first and latest dates of operation. Two sites in Orkney and Shetland were outside the area of our main cancer file, leaving 70 for our own analyses.

Friends of the Earth kindly supplied a list of 460 landfill sites used for disposal of toxic waste, a set of locations assembled by independent surveyors and already published in the media (e.g. The Times 8 August 1998). Dates of operation were not available but the great majority were visible on Ordnance Survey 'Landranger' 1:50 000 maps (based mainly on early 1970s revisions) and on available street maps: appearing there as sandpits, claypits, quarries, spoilheaps or segregated waste areas within major industrial sites. The map references supplied with the list generally corresponded with the marked sites and not with administrative offices such as country councils or waste disposal companies.

Finally, the locations of 307 principal hospitals in England and Wales, expanded slightly from an original list of 292 described in a previous report,[7] were re-examined. Such hospitals almost always possessed their own incinerators, and during the period of the survey they were notorious for their uncontrolled smoke. This arose through a legal anomaly under which 'crown property' was exempted from smoke emission regulations. The exact locations of the incinerators within hospitals were not identified and they were associated with the centres of the hospital sites.

For each migrant case and for a given list of hazards, the program first seeks the sources closest to each of the paired addresses. For each 'closest source' it measures individual address distances, constructing distributions and accumulating means so that relationships with closest sources at birth and at death can be compared. Individual birth-death differences are also accumulated and the mean difference examined for any departure from zero. The within-pair centrifugal differences are also expressed as simple ratios between numbers of children migrating away from or towards their nearest hazards. This is the simplest and generally the preferred form of presentation although all the findings were confirmed through the more complex quantitative statistics. In the Tables presented here, the two nearest hazards were usually the same geographical source but where they differed then the distances to the separate sources were differenced. There is also a program option which uses only the closest of the two nearest sources to measure the two distances and this was used to confirm findings and to construct graphical displays (see later). All such searches operate impartially on both birth and death addresses and the null hypothesis is one of symmetry between outward and inward movements. The results are disaggregated according to separate tumour types, the main tumour groups ('reticulo-endothelial' and 'solid') and the individual hazard sites.

First examinations of the incinerator neighbourhoods used the distance criteria used by Elliott *et al.*[1] Later analyses examined alternative distances, and some searches were restricted to incinerators whose operational time limits enclosed the birth date or the date of death of the child.

Results

Incinerators

Table 1 gives the results of several different analyses. Row 1 is a broad study of those migrations where either one or both addresses were within 7.5 km of an incinerator; while row 2 shows the same for a limit of 3.0 km. Each limit shows a statistically significant migration asymmetry. Examinations based upon 'less-certain' as well as upon 'certain' address pairs gave slightly greater asymmetries; (2131:1531 at 7.5 km and 933:558 at 3.0 km). Rows 3,4 restrict the hazard search to plants whose opening-to-closure periods enclosed the address dates of the child. The ratios were greater and the difference between the alternative boundaries (3.0 versus 7.5 km) was wider. The arithmetic differences between rows 1 and 3, and between rows 2 and 4, represent children excluded because their birth dates or dates of death were outside the operational time limits of otherwise eligible incinerators. Their migration ratios relative to these non-functioning sites were 1.03 (515:497) and 0.92 (181:196) and were not significant.

Rows 5,6,7 explore only those migrations which crossed specified annular boundaries (at 4.0, 5.0, 6.0 km); i.e., with one address inside and the other outside the designated circle. Migration ratios measured in this way are effectively estimates of the relative risks of the two zones. The objective was to seek the sharpest distinction between higher- and lower-risk zones. For a boundary of 5.0 km, with birth-related operational time limits, the outward:inward ratio was 2.01 (213:106). A subset restricted to those whose two addresses were within 15 km of the same incinerator gave a ratio of 2.27 (107:47) and this migration pattern is shown in Figures 1 and 2. The incinerator sites are registered jointly at the centre and the outward and inward migrations are shown separately in the two Figures. Directional biases, when attached to the incinerator locations, supplied no evidence of significant wind direction effects, On the contrary, such biases invariably reduced the migration ratios, confirming that the incinerators were themselves, or were very close to, the true centres of risk. Hospital incinerators likewise showed maximum discrimination at 5.0 km, giving a significant outward:inward ratio of 1.69 (919:544).

Row 8 follows the suggestion of Elliott *et al.*[1] that older incinerators might be more toxic than more modern ones and it limits examination to those which began operation prior to 1955. The outward:inward ratio at 5.0 km was 2.26, tending to confirm the suggestion, while the arithmetic difference between rows 6 and 8 (19:20) seemed to exonerate the more modern plants.

Solid toxic-waste landfill sites

The 460 landfill sites were licensed to accept solid waste of greater than normal toxicity. Many had accepted such waste before the licensing scheme was introduced but precise dates of first acceptance were not available. The locations were examined in a manner similar to the incinerators and Table 2 displays results analogous to Table 1. There was no evidence here of any outward-inward asymmetry; nor at several alternative boundaries examined.

Table 1 Outward and inward migration near 70 Municipal waste incinerators

	Radial limits (km)			Migrations between birth and death			
	Address X	Address Y	(pair-rule)	Outward No. of children	Inward No. of children	**Ratio**	***P***
All accurate address pairs[a]							
1	0 to 7.5	0 to 2000	(either <7.5)	1012	808	1.25	<0.001
2	0 to 3.0	0 to 2000	(either <3.0)	392	310	1.27	<0.005
Time limit and birth date relevance[a]							
3	0 to 7.5	0 to 2000	(either <7.5)	479	311	1.54	<0.001
4	0 to 3.0	0 to 2000	(either <3.0)	211	114	1.85	<0.001
Discriminating radial boundaries[b]							
5	0 to 4.0	4 to 2000	(crossing 4.0)	207	112	1.85	<0.001
6	0 to 5.0	5 to 2000	(crossing 5.0)	213	106	2.01	<0.001
7	0 to 6.0	6 to 2000	(crossing 6.0)	237	137	1.73	<0.001
Pre-1955-startup incinerators only[b]							
8	0 to 5.0	5 to 2000	(crossing 5.0)	194	86	2.26	<0.001

[a] Either one or two addresses inside the limit.

[b] One address inside and the other outside the limit.

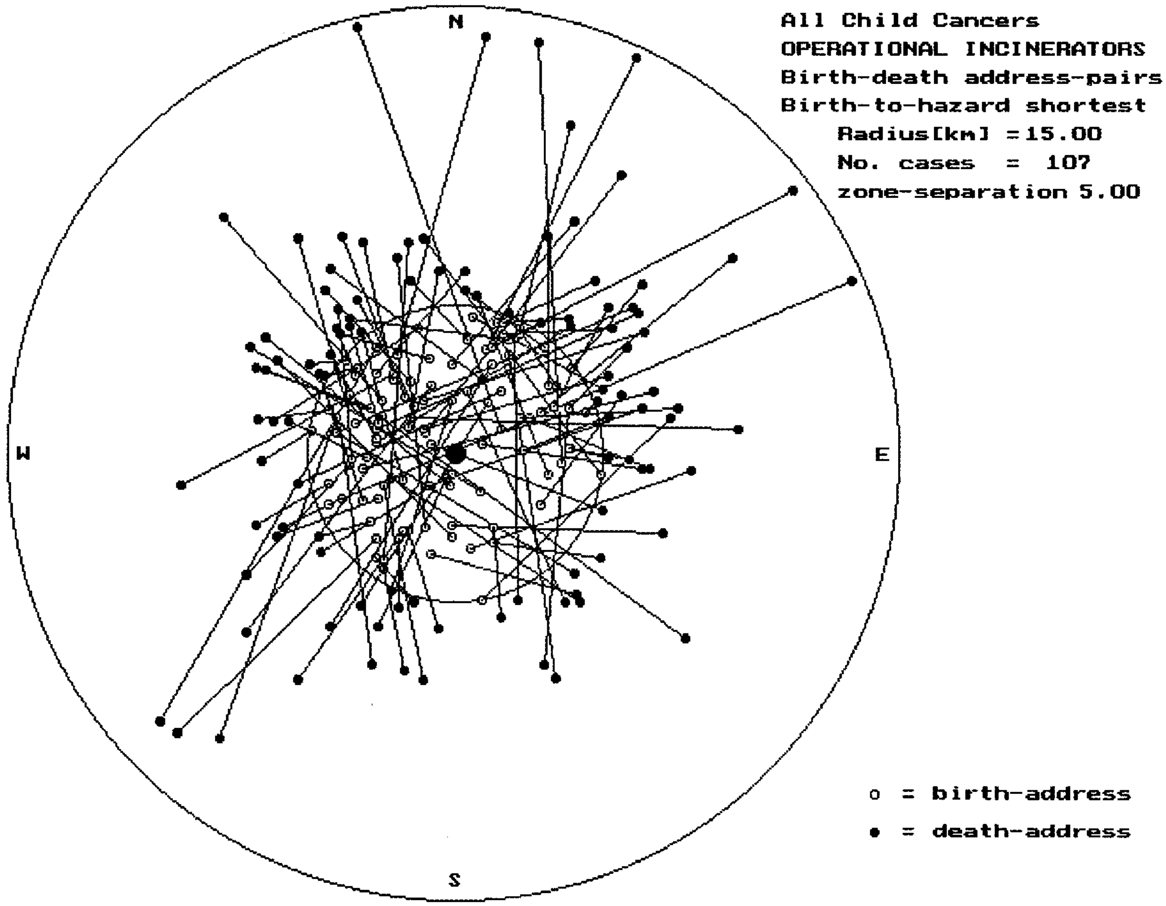

Figure 1 Outward migrations from the vicinities of municipal incinerators

Internal heterogeneities

The majority of individual landfill sites conformed with the neutral overall pattern shown in Table 2. However, six of the 460 showed outward:inward ratios of 6:1, 8:0, 10:5, 11:3, 11:4, and 12:1; while there were no excesses of ⩾5 in the opposite direction. Detailed map studies showed that all six were located in heavily industrialized areas, often shown specifically as industrial spoil heaps. All were closely surrounded by groups of factories, steelworks, oil tanks and gasworks: or by railways, railyards, docks, canals, and motorways. (Appendix 1 for details.)

The incinerator sites also showed a number of highly asymmetric individual migration ratios. Ten of the 70 sites showed ratios of 7:1, 8:3, 11:1, 21:14, 25:16, 6:0, 12:6, 15:4, 28:3, and 12:4; while there were no comparable asymmetries in the opposite direction. Between them, these 10 sites accounted for much of the overall asymmetry. It is difficult to say whether this represents the tail of a continuous asymmetric distribution; or whether the more extreme values might reflect special toxicities of some plants; or else a geographical association with other toxic sources. All these high-ratio sites were located in densely populated urban areas, all but one of them had opened before 1945, and they were in continuous use throughout the survey. All were closely associated with other potentially toxic sources including railways, railyards, docks, canals, steelworks, engineering and other factories, oil tanks, crematoria and hospital incinerators. (Appendix 1.)

There were no evident predilections for specific tumour or leukaemia types near the landfill sites or the hospitals or the municipal incinerators: or near the most ‘toxic’ subsets of each: when compared with total numbers of cases. Results for the grouped ‘reticulo-endothelial’ tumours did not differ from the remaining ‘solid’ tumours.

Discussion

These results for childhood cancers and municipal incinerators are qualitatively concordant with those obtained by Elliott *et al.*[1] for (mainly) adult cancers; and also with results for childhood cancers around hospital incinerators and other large-scale high-temperature combustion sources.[7] They contrast sharply with the negative findings for the landfill sites. As with previous studies of proximities of childhood cancers to industrial sites, and of exposures to pre-natal medical radiation, the excesses were similar for leukaemias and solid tumours of all types. This is as we might expect for agents with systemic access to the DNA/RNA of all types of fetal cells.

Outward:inward ratios derived from migrations which cross the line between a narrow inner and a broad outer zone, can be treated as estimates of local relative risks. They were much greater than the relative risks reported for ‘all-age’ cancers. The differences possibly reflect (1) an increased susceptibility in rapidly growing fetal tissues, (2) the relative variability of latent

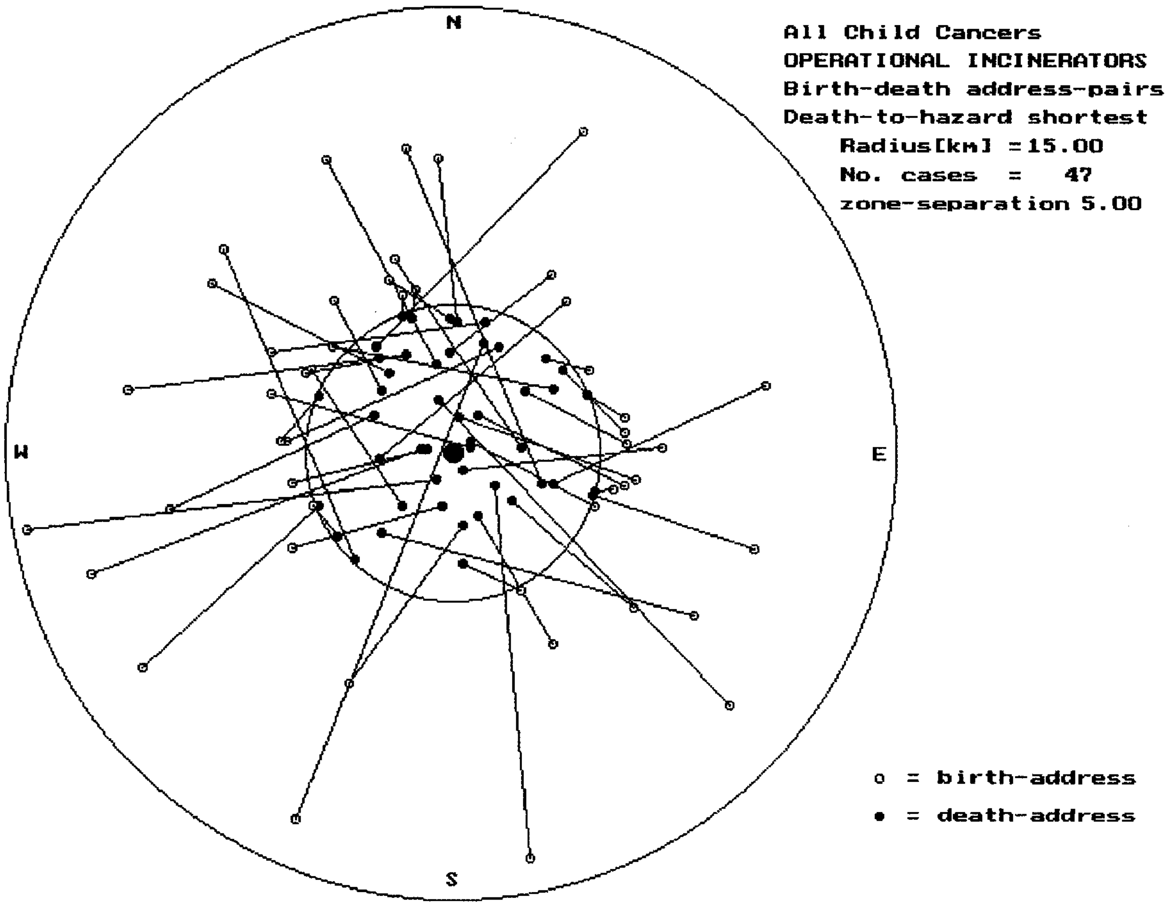

Figure 2 Inward migrations towards the vicinities of municipal incinerators

Table 2 Outward and inward migration near 460 toxic-waste landfill sites

	Radial limits (km)			Migrations between birth and death			
	Address X	Address Y	(pair-rule)	Outward No. of children	Inward No. of children	**Ratio**	***P***
All accurate address pairs							
1	0 to 7.5	0.0 to 2000	(either <7.5)	1445	1398	1.03	ns
2	0 to 3.0	0.0 to 2000	(either <3.0)	481	463	1.04	ns
Discriminating radial boundaries							
3	0 to 5.0	5.0 to 2000	(crossing 5.0)	547	596	0.92	ns
4	0 to 2.0	2.0 to 2000	(crossing 2.0)	174	186	0.94	ns

intervals for adult cancers, (3) dilution of local adult exposures by unrecorded migrations between dates of initiation and registration, and (4) extensive contamination in adults by cancers with known non-incinerator causes, especially smoking.

There must of course be caveats about results obtained from a dataset with no controls appropriate to the current objectives. The available controls had been selected for an entirely different purpose and had been matched geographically for place of death; and also because they had not moved from the Local Authority of their births. It was for this reason that other approaches had to be used to explore the nature of the demonstrated geographical heterogeneities and it is also for this reason that social, demographic and other selective effects cannot finally be excluded.

Potential demographic artefacts in the childhood results have been examined in detail elsewhere. The main caveat is that a continuing net outward migration of the general child population from these and from similar localities could exaggerate or mimic an apparent toxic effect. This could arise from large-scale local demolitions or from an age-related circulation of the population within the existing housing stock. For example, expectant mothers might live at first with their 'inner-city' parents and later move or return to less industrial zones and to areas less well-provided with hospitals. However, the migration asymmetries around incinerators and other effluent sources are much greater than those reported near to non-industrial urban foci and 'non-combustion' industrial markers such as football grounds, cathedrals, biscuit makers, paper manufacturers, nuclear establishments, TV transmitters, mail-order firms, landfill waste sites; or random postcodes.[5] They are also too great to be explained easily as general demographic migrations. The observed migrations among the cancers occurred within birth-to-death intervals of about 6 years and if these rates had continued within the general population over the full 40-year span of the birth dates, the surrounding zones would have been depopulated. Incidentally, the main caveat about the measured excesses of cancer births per 1000 postcodes near potentially hazardous sites, is that the local postcodes may be over- rather than under-populated. In the face of the concordant findings, this opposition suggests that neither objection can be valid.

The question also arises whether the migrants are socially different from the non-migrants, whether the results among the latter might spring from some hidden selective process related to prolonged survival or late age at death, and whether the inferences for migrants can be generalized to the full set of cancer children. Age biases were easily excluded and prolonged survival, unusual in the period that these data were collected, might more readily be associated with migration towards urban centres of medical care, than away from them. It was also shown that migrant cancers tend to move away from the birthplaces of other migrants, presumably reflecting their joint proximities to local hazards. Not only that; they also tended to move away from the birthplaces of non-migrants. Only for the deathplaces of other migrants were the outward:inward movements neutral.

It is difficult to say whether the apparent carcinogenic risks near incinerators might stem from (some of) the plants themselves or from other hazards in their near environments. In favour of the latter, all the most 'toxic' incinerators were close to industrial sources of kinds implicated in earlier studies, as were the few exceptional landfill sites. On the other hand, concordance with hospital incinerators suggests a common direct effect; as does the observed limitation to the operational time spans of the municipal facilities. For the time being we must probably suppose that the effect stems from large-scale combustion processes as a whole, of which the incinerators are but one component.

It would probably be worth re-examining the data on adult cancers (especially lung and liver) near those incinerators giving the most extreme ratios for childhood cancers. A locally enhanced risk might still not discriminate clearly between a direct effect, one mediated through geographical confounding, or a combined effect, but it might at least indicate whether the pathway was atmospheric rather than social.

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References

1 Elliott P, Shaddick G, Kleinschmidt I *et al*. Cancer incidence near municipal solid waste incinerators in Great Britain. *Br J Cancer* 1996; **73:**702–10.

2 Knox EG, Gilman EA. Leukaemia clusters in Great Britain. 2. geographical concentrations. *J Epidemiol Community Health* 1992;**46:**573–76.

3 Knox EG. Leukaemia clusters in childhood: geographical analysis in Britain. *J Epidemiol Community Health* 1994;**48:**369–76.

4 Knox EG, Gilman EA. Spatial clustering of childhood cancers in Great Britain. *J Epidemiol Community Health* 1996;**50:**313–19.

5 Gilman EA, Knox EG. Geographic distribution of birth places of children with cancer in the UK. *Br J Cancer* 1998;**77:**842–49.

6 Knox EG, Gilman EA. Hazard proximities of childhood cancers. *J Epidemiol Community Health* 1995;**51:**151–59.

7 Knox EG, Gilman EA. Migration patterns of children with cancer in Britain. *J Epidemiol Community Health* 1998;**52:**716–26.

Appendix

Map references of high-ratio landfill sites

6:1	469.7E 170.4N Reading
8:0	451.2E 521.8N Billingham
10:5	437.1E 334.8N Derby
11:3	379.9E 397.2N Manchester
11:4	434.7E 389.8N Sheffield
12:1	386.5E 347.3N Stoke-on Trent

Map references of high-ratio incinerators

7:1	375.7E 429.0N Accrington
8:3	510.4E 429.9N Hull
11:1	427.6E 434.1N Leeds
21:14	458.2E 339.1N Nottingham
25:16	549.7E 186.6N Dagenham
6:0	523.4E 166.6N Morden
12:6	405.6E 279.8N Birmingham[a]
15:4	410.8E 284.7N Birmingham[a]
28:3	408.2E 286.9N Birmingham[a]
12:4	391.7E 299.9N Wolverhampton
145:52	Total of above 10 sites.
68:54	Total for remaining 59 sites

[a] The 5km zones around these three sites overlap but there is no duplicate counting of the children involved.

Map references are given in km and tenths of kms from map origins.