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Stillbirth rates around the nuclear installation at Sellafield, North West England: 1950–1989

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Background The aim of the study was to investigate whether proximity to the nuclear installation at Sellafield, in Cumbria, North West of England, increases the risk of stillbirth in the resident population. The cohort consisted of all 256 066 live and 4034 stillbirths to mothers usually domiciled in Cumbria, 1950–1989.

Methods The study was a retrospective cohort analysis allowing for year of birth, social class and birth order using: (i) Poisson probability mapping, (ii) comparison of cumulative observed and expected numbers of stillbirths by distance from Sellafield, (iii) logistic regression of stillbirth risk in relation to distance and direction from Sellafield.

Results Poisson probability mapping of stillbirths within 25 km of Sellafield provided no evidence to suggest that proximity to Sellafield increased the risk of stillbirth, either overall or in any specific direction. Comparison of the cumulative observed and expected numbers of stillbirths also showed no increased risk with proximity to Sellafield. Logistic regression analysis of all Cumbrian births supported these results, showing, in particular, that distance from Sellafield did not significantly influence stillbirth risk ($P = 0.30$). Although there was significant variation in stillbirth risk with direction ($P = 0.0004$), this was due to stillbirths in areas much further than 25 km from Sellafield. There was no significant effect with distance from Sellafield within any of six directional sectors ($P > 0.05$).

Conclusions There was no evidence to suggest that proximity to Sellafield increases the risk of stillbirth in the resident population.

Keywords Stillbirths, environmental radiation, cohort study

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There has been concern that women living near to the nuclear reprocessing plant at Sellafield, West Cumbria, may have an increased risk of having stillborn children.[1,2] However, neither a consideration of stillbirth rates in electoral wards between 1981 and 1992[1] nor an analysis of stillbirth numbers in the county district around Sellafield between 1949 and 1981[2] found evidence to support this concern.

The aim of the present study was to test the hypothesis that proximity to Sellafield increases the risk of stillbirth in the resident population, considering the time period from the beginning of nuclear operations at Sellafield in 1950 up to 1989. It differs from previous studies in the incorporation of individual level risk factors for stillbirth and the use of the much finer geographical reference of unit postcodes rather than wards or administrative districts. In particular, the use of individual level data, geographically referenced by unit postcodes and stored within a geographical information system (GIS), allowed analysis at a range of user-defined spatial areas.

Methods

The study area considered was the area currently defined as Cumbria.[3] The cohort studied consisted of all live and stillbirths born to mothers usually resident in the study area during the period 1 January 1950 to 30 September 1989. During this period stillbirth was defined as fetal death after 28 weeks' gestation.[4,5] Three statistical analyses were undertaken. The first two analyses compared the observed number of stillbirths within a 25 km radius of Sellafield with the expected number as estimated from the stillbirth rate in the remainder of Cumbria. The third analysis was a logistic regression analysis[6] of stillbirths in the whole of Cumbria investigating the effect on stillbirth risk of the distance and direction of each birth from Sellafield.

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Table 1 Ascertainment of live and stillbirths, excluding multiple births

	Within 25 km of Sellafield			Outside 25 km of Sellafield						
	Stillbirths			Stillbirths			Postcode unknown		Totals	
Section	Live births	No.	Rate × 10^3	Live births	No.	Rate × 10^3	Livebirths	Stillbirths	Livebirths	Stillbirths
a) Registered births within Cumbria to mothers domiciled in Cumbria	54 716	877	15 8	199 276	3042	15.0	1404	7[a]	255 396	3926
b) Registered births outside Cumbria to mothers domiciled in Cumbria	28	1	34.5	2037	85	40.1	–	–	2065	86
c) Unregistered births to mothers domiciled in Cumbria	2	10	–	7	19	–	1	7	10	36
Total births	54 746	888	16.0	201 320	3146	15.4	1405	14	257 471	4048

[a] Five of these stillbirths were within the 25 km zone around Sellafield

The Cumbrian database

The study was based on a database containing birth registration details of all births to mothers normally domiciled in Cumbria between 1950 and 1989.[7,8] In summary, all live and stillbirth registrations for the study area were obtained from the Office for National Statistics (ONS), formerly the Office of Population Censuses and Surveys, and entered into a computer database (Table 1, section a). Hospital records in Cumbria were searched for details of additional stillbirths to mothers resident in Cumbria. Maternity records in regional referral centres outside Cumbria, i.e., Newcastle, Hexham and Lancaster, were searched for details of live and stillbirths to mothers usually resident in Cumbria (Figure 1 and Table 1, section b). The birth registrations corresponding to these additional stillbirths were requested from ONS and the details added to the database. For a small number of births, predominantly stillbirths, ONS were unable to identify the relevant birth registrations and in these instances the birth details from hospital records were added directly to the database (Table 1, section c).

The mother's residence at the birth of the child was postcoded using Post Office postcode directories[9] and hence each birth was assigned a grid reference using the Post Office Postzon file.[10] The Postzon file provides grid references accurate to 100 m for the first property in each unit postcode. The father's occupation, as recorded on the birth certificate, was coded and hence the social class was derived.[11] Algorithms based on parents' names were used to identify siblings and multiple births and to assign birth order. Whether or not the father was recorded on the birth certificate was also flagged. A small percentage of the cohort, 0.6% of live births and 0.4% of stillbirths, could not be postcoded (Table 1) as the address on the birth registration was illegible or the location could not be identified. These births were excluded from any further analysis, as were multiple births as they may not represent independent events.

Poisson probability mapping of stillbirth numbers by distance annuli and direction from Sellafield

A comparison was made of the observed and expected numbers of stillbirths to mothers domiciled in distance annuli around Sellafield, by decade. Taking the point location of Sellafield as NY 027 039,[1] circles of radius 5, 10, 15, 20, 25 km centred on Sellafield were drawn and the distance annuli defined as the areas between successive circles (except for the innermost 'annulus' which was actually the area defined by the innermost circle) (Figure 2). A point-in-polygon overlay was performed with the GIS Arc/Info[12] to assign each birth to a distance zone.

Figure 1 Cumbria and the major maternity referral centres outside Cumbria in the North of England

Expected stillbirth rates within each area were estimated from rates in the remainder of Cumbria. The logistic regression facilities in the statistical package Stata[13] were first used to model how the probability of a stillbirth varied with social class, year of birth, birth order, and whether or not the father was recorded on the birth certificate, for births *outside* the 25 km zone around Sellafield. As the presence or absence of the father's name on the birth certificate was strongly confounded with social class it was treated as another category in the social class classification. The baseline for the presentation of results for social class was taken to be social class IIIm as the largest number of births was in this social class. These probabilities were then used to estimate the expected number of stillbirths *within* the 25 km zone.

The expected number of stillbirths in each annulus for each decade was compared with the observed number of stillbirths using Poisson probability mapping.[14,15] Since the hypothesis under investigation was that there was an increased risk of stillbirth closer to Sellafield, the Poisson probabilities were computed when the observed number of stillbirths was greater than

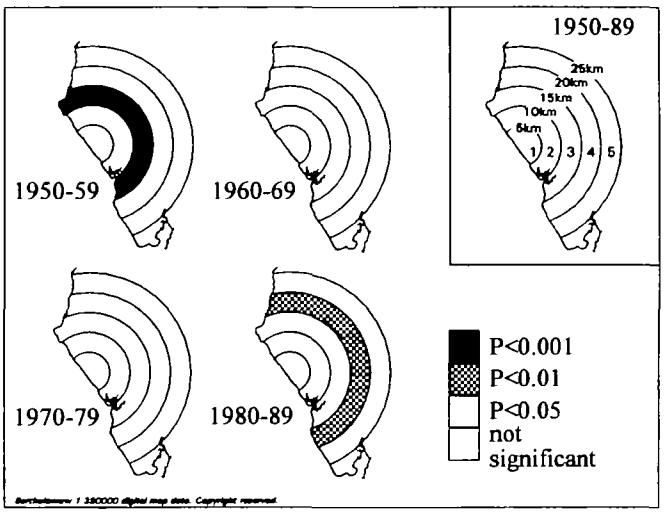

Figure 2 Distance annuli around Sellafield indicating those where the observed number of stillbirths was significantly higher than expected

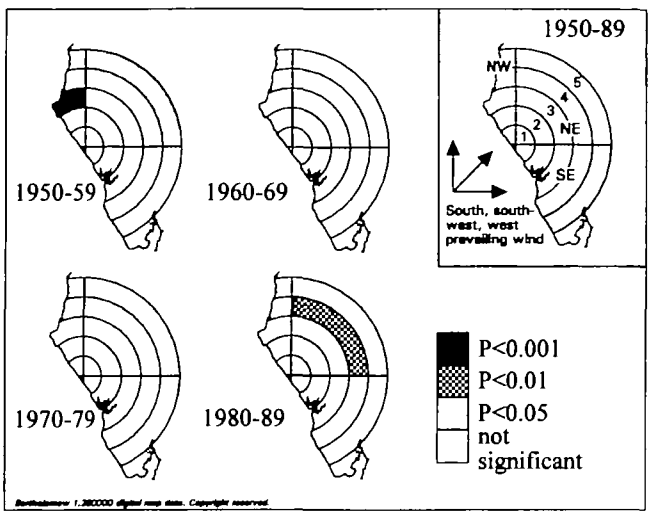

Figure 3 Sub-sectors within the 25 km zone around Sellafield indicating those where the observed number of stillbirths was significantly higher than expected

the expected and a one-tailed significance test was used. Annuli where the observed numbers of stillbirths were greater than the expected number were mapped when the Poisson probability was significant at the 0.001, 0.01 and 0.05 levels.

In addition, the 25 km zone was divided into the three directional sectors: north west, north east and south east, with the origin centred on Sellafield (Figure 3). These sectors enabled the investigation of potential effects downwind of the plant; assumed to be north east of the installation given the south, south-west or west prevailing wind system in the British Isles.[16] The three directional sectors were overlaid with the five distance zones to produce 15 sub-sectors (Figure 3). Poisson probability mapping was undertaken for all sectors and sub-sectors.

Cumulative observed and expected stillbirth numbers by distance from Sellafield

The cumulative observed and expected numbers of stillbirths within the 25 km zone around Sellafield were calculated for increasing distance from Sellafield; both for the entire zone and within the directional sectors. The expected stillbirth numbers were derived, as outlined above, from the logistic regression model describing stillbirths outside the 25 km zone. The 95% confidence interval (CI) for the expected number of stillbirths was derived from the standard error of the probability predicted by the logistic regression model.

Logistic regression analysis of stillbirths throughout Cumbria

To investigate further the observed pattern of stillbirth risk in relation to Sellafield, a logistic regression analysis was undertaken considering all births in Cumbria. This analysis included, as explanatory variables additional to those considered in the logistic regression analysis described above; firstly, a monotonically decreasing function of the distance, d, of each birth from Sellafield, which was taken to be 1/d, and, secondly, the directional bearing of each birth from Sellafield. Births were grouped into six directional categories of approximately equal numbers of births (Figure 4). Distance and direction were considered independently of each other to avoid spurious effects of distance which might be introduced by the inclusion of greater numbers of births at greater distances due to the widening out of directional categories. Finally, the possible effects of distance within each directional category were considered. These explanatory variables allowed the modelling of a putative risk factor which may increase with proximity to Sellafield and which may be higher in particular directions.

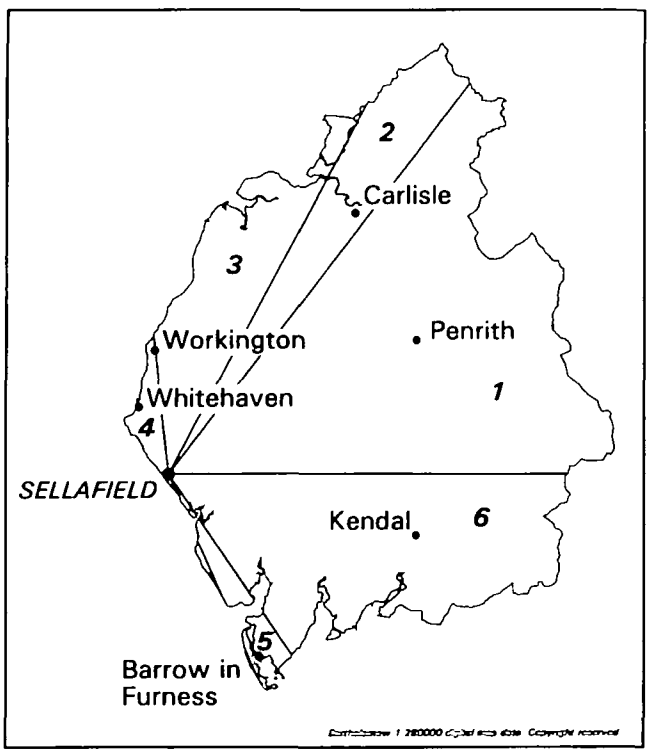

Figure 4 Cumbria divided into six directional categories of approximately equal numbers of births

Table 2 Odds ratios for stillbirth by year of birth, social class and birth order for births outside the 25 km zone around Sellafield

Explanatory variables	No. of births	Odds ratio	95% CI
Year of birth—quadratic	–	0.9989	0.9988–0 9990
Social Class			
I	9288	0.59	0.47–0.75
II	33 460	0.88	0.79–0.98
IIIn	17 685	0.77	0.66–0.89
IIIm	82 694	1.00	–
IV	31 731	1.12	1.01–1 24
V	17 010	1.13	0 99–1.28
Armed Forces	4466	0.90	0.71–1.13
Social class unknown	734	1.21	0.68–2.14
Father not recorded on birth certificate	7398	2.19	1.90–2.53
Birth order			
1	123 560	1.00	–
2	53 990	0.63	0.57–0.70
3	18 331	0.81	0.71–0.93
4	5682	0.91	0.73–1.12
≥5	2903	1.35	1.07–1.71

Results

The total numbers of live and stillbirths within and outside a 25 km radius of Sellafield and the sources of ascertainment are shown in Table 1.

The odds ratios (OR) for the risk of stillbirth for all births outside the 25 km zone around Sellafield, estimated using logistic regression, are shown in Table 2.

The stillbirth rate in Cumbria has fallen dramatically, from 24.6 per 1000 births in 1950 to 4.7 per 1000 births in 1989. The logistic regression analysis showed that this decrease over time was best modelled by a quadratic term in year (which corresponds to, for example, an OR of 0.90 in 1960, 0.64 in 1970 and 0.37 in 1980 relative to a baseline of 1.0 in 1950). There was a trend for risk of stillbirth to increase with decreasing social class in every decade ($P < 0.001$ for a linear test for trend). The risk of stillbirth varied with birth order and this variation was modelled by using five categories: birth order 1, 2, 3, 4 and ≥5. Observed and expected stillbirth numbers over time, within and outside the 25 km zone around Sellafield, are presented in Figure 5 The expected numbers of stillbirths in both instances were estimated from the logistic regression model describing stillbirths outside the 25 km zone.

The standardized stillbirth ratio (SSR) within the 25 km zone around Sellafield, standardized using the stillbirth rate in the remainder of Cumbria adjusted for year of birth, social class and birth order, was 1.02 (95% CI : 0.95–1.09), indicating that there was no significant difference in the stillbirth rate in the areas within and outside 25 km of Sellafield.

The Pearson χ^2 test[17] (χ^2 = 1288, 1477 d.f., $P = 0.9999$) and a goodness of link test of the logit link[18] ($P = 0.701$) both suggested that the model was acceptable. An interaction term for each of the three covariates was entered into the logistic regression model but did not appreciably improve the model fit ($P > 0.05$ for each term).

Poisson probability mapping of stillbirth numbers by distance annuli and direction from Sellafield

Figures 2 and 3 show the Poisson probability mapping of stillbirth numbers by distance annuli and distance/directional sub-sector. The numbers of births, stillbirths and the ratio of the observed to expected numbers of stillbirths for each areal unit are presented in Table 3.

The excess of stillbirths in the 15 km annulus in 1950–1959 (Figure 2) corresponds with an excess of stillbirths in the 15 km north west sub-sector (Figure 3) for the same time period. In the 1980–1989 time period the excess in the 20 km annulus (Figure 2) corresponds with an excess in the 20 km north east sub-sector (Figure 3).

The five stillbirths within the 25 km zone around Sellafield that could not be postcoded (Table 1) and had therefore been omitted from the analysis were assigned to the closest postcodes to Sellafield consistent with the very limited information on the stillbirth registrations, but this did not materially influence the results.

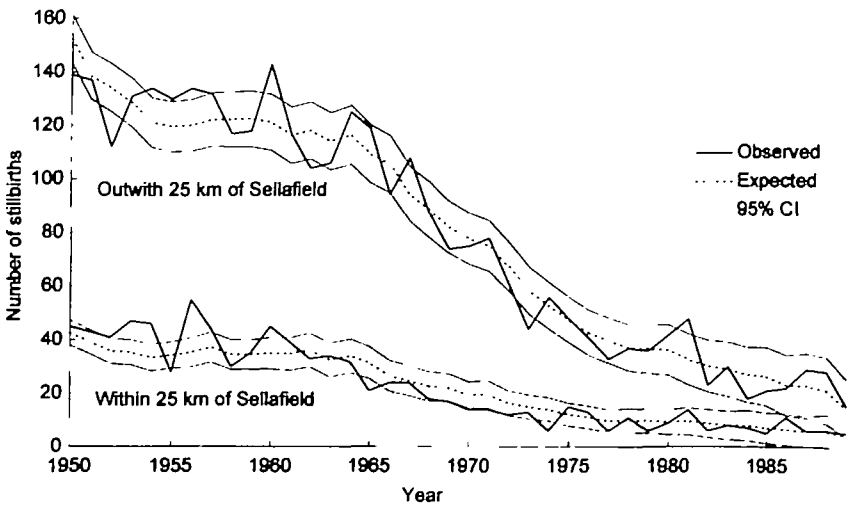

Figure 5 Observed and expected numbers of stillbirths within and outside 25 km of Sellafield by year: 1950–1989

Table 3 Numbers of births, stillbirths and the observed/expected stillbirth ratio (O/E) for distance annuli, direction sector and distance/direction sub-sector by decade, 1950–1989, (* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$)[a]

Annulus	Distance (km)	1950–1959			1960–1969			1970–1979			1980–1989			Total births	Total stillbirths		
		Births	Stillbirths	O/E	Births	Stillbirths	O/E	Births	Stillbirths	O/E	Births	Stillbirths	O/E		Observed	Expected	O/E
NW																	
1	5	104	0	0	162	3	1.09	142	1	0.70	125	0	0	533	4	7.1	0.56
2	10	1546	40	1.14	1846	28	0 85	1292	8	0 52	1341	11	1.34	6025	87	91 4	0.95
3	15	5666	167	1.29***	5920	116	1.06	4265	39	0.76	4124	21	0.78	19 975	343	317.5	1.08
4	20	2000	51	1.17	1725	33	1.07	1241	10	0.68	1288	13	1.64	6254	107	99.6	1.07
5	25	3961	88	0.97	4266	73	0.94	3108	32	0 87	3130	18	0 90	14 465	211	225.3	0.94
Total		13 277	346	1.14**	13 919	253	1.00	10 048	90	0 75	10 008	63	0 99	47 252	752	740 8	1.02
NE																	
1	5	117	1	0.37	103	3	1.68	43	0	0	60	1	2.94	323	5	5.2	0.96
2	10	30	1	1 52	37	1	1.79	32	0	0	40	0	0	139	2	1.7	1 18
3	15	937	25	1.10	897	16	0.92	512	7	1.11	460	3	1.03	2806	51	49.2	1 04
4	20	146	1	0.28	155	0	0	105	2	1.71	145	4	5.06**	551	7	8 2	0.85
5	25	235	10	1.90*	238	1	0.25	163	0	0	155	1	1 11	791	12	11 9	1.01
Total		1465	38	1.09	1430	21	0.79	855	9	0 90	860	9	1 75	4610	77	76.3	1 01
SE																	
1	5	455	11	1.35	544	4	0.51	311	3	0.98	295	0	0	1605	18	20.7	0.87
2	10	165	2	0.58	171	1	0.33	84	1	1.09	105	1	1.64	525	5	8 2	0.61
3	15	139	5	1 64	159	2	0.73	82	1	1.09	52	0	0	432	8	7.0	1.14
4	20	182	6	1 44	151	0	0	98	3	2 88	92	1	1.96	523	10	8.3	1 20
5	25	197	6	1.39	191	6	1.85	148	3	1.85	151	3	3.45	687	18	10 1	1.78*
Total		1138	30	1.28	1216	13	0.67	723	11	1 47	695	5	1 30	3772	59	54.2	1.09
All sectors																	
1	5	676	12	0.92	809	10	0.80	496	4	0 87	480	1	0.39	2461	27	33 0	0.82
2	10	1741	43	1.09	2054	30	0.82	1408	9	0.89	1486	12	1.33	6689	94	101.3	0 93
3	15	6742	197	1.27***	6976	134	1.03	4859	47	0 80	4636	24	0 80	23 213	402	373.8	1.08
4	20	2328	58	1.08	2031	33	0.91	1444	15	0.55	1525	18	1.95 **	7328	124	116.1	1.07
5	25	4393	104	1.03	4695	80	0 95	3419	35	0.81	3436	22	1.01	15 943	241	247 3	0.97
Total		15 880	414	1.14	15 836	287	0.96	11 626	110	0.80	11 563	77	1.06	55 634	888	871.5	1 02

[a] The probability of obtaining a number of stillbirths greater than or equal to that observed was:

$$\sum_{x=O_{ij}}^{\infty} \frac{e^{-E_{ij}} E_{ij}^{x}}{x!}$$

where O_{ij} is the observed number of stillbirths in annulus i and time period j, E_{ij} is the expected number of stillbirths in annulus i and time period j, estimated from the logistic regression model describing stillbirth rates in Cumbria outside the 25 km zone around Sellafield.

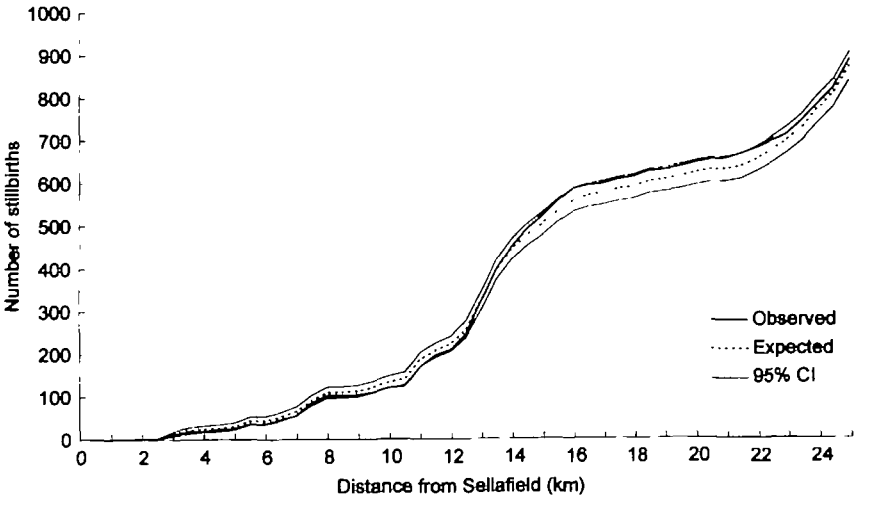

Figure 6 Cumulative observed and expected numbers of stillbirths 1950–1989 by distance from Sellafield

Cumulative observed and expected stillbirth numbers by distance from Sellafield

Figures 6 and 7 show the cumulative observed and expected numbers of stillbirths within both the entire 25 km zone around Sellafield and the three directional sectors. For all births within the 25 km zone (Figure 6), the observed number of stillbirths was below that expected until approximately 14 km from Sellafield, which is consistent with the Poisson probability mapping results by annuli (Figure 2). A similar pattern was observed in the north west sector (Figure 7a), consistent with the excess of stillbirths in the 15 km north west sub-sector in 1950–1959 (Figure 3). In the north east sector (Figure 7b) the observed was close to the expected over the whole range considered. The observed number of stillbirths was consistently less than the expected in the south east sector (Figure 7c), until 23 km where it became higher. The observed number of stillbirths was within the 95% CI in all analyses except between 14 km and 22 km in the north west sector (Figure 7a).

Logistic regression analysis of stillbirths throughout Cumbria

Results of the logistic regression analyses of stillbirths throughout Cumbria, with the additional explanatory variables of distance (model a) or directional bearing of each birth from Sellafield (model b), are presented in Table 4; the OR for the other explanatory variables were very close to those presented in Table 2 for births outside the 25 km zone around Sellafield. There was a non-significant decreasing risk of stillbirth with increasing proximity to Sellafield. There was a significantly increased risk of stillbirth in direction category 2 and a non-significant increased risk of stillbirth in direction category 3, relative to the baseline category 1. Categories 2 and 3 are north east of Sellafield, and may be considered downwind. The increased risk in category 2 was still significant ($P < 0.01$) when it was compared with the remaining five categories considered as a group. This elevated risk was due to an excess of stillbirths in some areas far outside the 25 km zone around Sellafield. There was no significant variation in risk of stillbirth with distance within any of the six directional categories ($P > 0.05$ for all categories). Inspection of residuals by distance from Sellafield, within directional sectors and time periods, confirmed the absence of any obvious spatial pattern of deviation from the model.

Discussion

The study is estimated to have approximately 80% power, at the 95% confidence level, to detect a relative risk of stillbirth of 1.5 in the 5 km annulus around Sellafield.[19]

National statistics show a decline in the stillbirth rate in England and Wales from 23.0[20] to 4.7 per 1000 births[21] in the 40 years from 1950. This trend was closely followed in Cumbria although rates were generally higher. Likewise the trend with social class and single mothers reflected that reported in national statistics.[22,23]

The assumption that exposure to emissions from Sellafield may be modelled as the inverse of distance can be only an approximation. The function 1/d was chosen by analogy with its use by Bithell[24] as a score for each birth in linear risk score tests for excess risk around a point source.

Meteorological factors may affect the deposition of pollutants such that exposure may not decrease monotonically with increasing distance and may not peak downwind of the source.[25] However, Jones *et al.*,[26] have suggested that, in general, around Sellafield, an assumption of an exponential decrease in radionuclide deposition is reasonable and this can be closely approximated by the inverse of distance. Release of pollutants from a high chimney stack may result in deposition occurring at some distance from the source, with a low level of material deposited immediately around the source.[27] To allow for the possibility of such an effect, those births within 5 km of Sellafield were removed from the logistic regression analysis but this did not appreciably change the results. It was assumed that

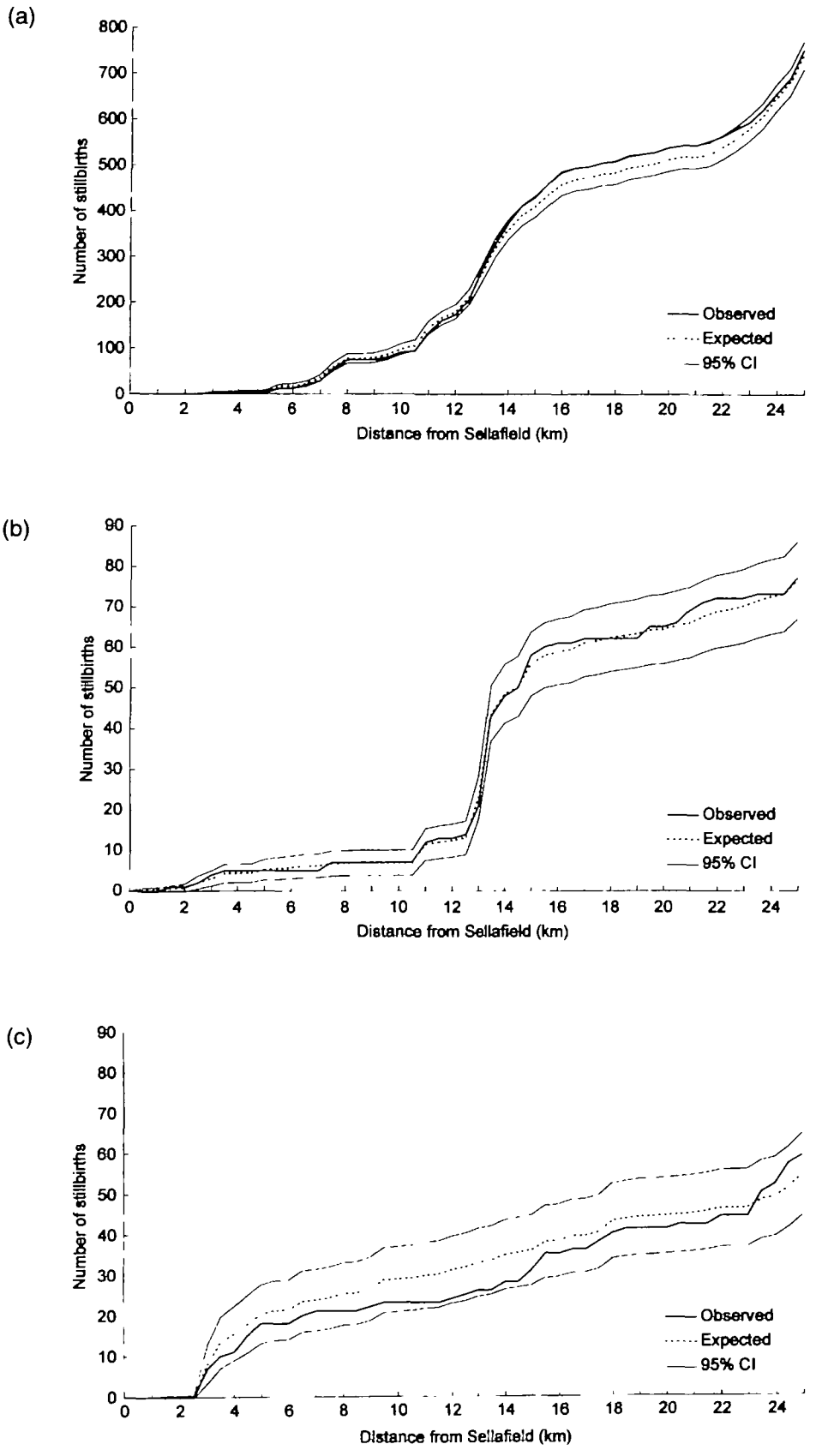

Figure 7 Cumulative observed and expected numbers of stillbirths 1950–1989 by distance from Sellafield for (a) the north west sector, (b) the north east sector, and (c) the south east sector

Table 4 Odds ratios for stillbirth by distance and direction of each birth from Sellafield for the whole of Cumbria, controlling for the effects of year of birth, social class and birth order

Explanatory variables	No. of births	Odds ratio	95% CI
Model a			
Inverse of distance from Sellafield (km)	–	0.66	0.30–1.49
Model b			
Direction from Sellafield			
Category 1	42 852	1.00	–
Category 2	43 403	1.12	1.00–1.24
Category 3	42 947	1.07	0.96–1 19
Category 4	43 919	1.01	0.90–1.12
Category 5	43 098	0.96	0.86–1.07
Category 6	43 881	0.88	0.78–0.98

Sellafield was a single point location. However, radioactive material from Sellafield enters the atmosphere from a number of points and through discharges into the sea.[28]

Summary of results and comparison with previous studies

The three analyses undertaken in the present study, in which we were able to estimate the expected stillbirth rate using two different methods, are consistent in their lack of support for an increased stillbirth rate closer to Sellafield.

The Poisson probability mapping showed geographical heterogeneity of risk of stillbirth within a radius of 25 km of Sellafield, but found no evidence for increased risk with increasing proximity to Sellafield or in any particular direction. The excess risk was predominantly in two areas: one between 10–15 km from Sellafield in the north west sector in the time period 1950–1959 and the other between 15–20 km from Sellafield in the north east sector in the time period 1980–1989. The first area was highly populated (5666 births) and hence there was greater power to detect a significant excess. There was also a slight excess of stillbirths in all time periods in the south east sector between 20–25 km from Sellafield which was only significant when the four decades were considered together.

The plotting of the cumulative observed and expected numbers of stillbirths by distance from Sellafield has the potential to show an excess risk of stillbirth close to Sellafield. Whilst Figure 7b (north east sector) indicates some excess up to 5 km from Sellafield this was well within the CI of the expected number of stillbirths and reflects less than one excess stillbirth.

In the logistic regression model, the large number of births distant from Sellafield dominated the estimates of the effects of demographic factors, effects which were explicitly estimated from births outside the 25 km zone in the previous analyses. On the other hand, births close to Sellafield have dominated in estimating the effect of variation of stillbirth risk with the inverse of distance from Sellafield. The closest birth to Sellafield was at approximately 0.5 km from the point grid-reference assigned to Sellafield. The logistic regression model (Table 4) indicated that the odds of stillbirth at distance, d, from Sellafield compared to the odds at this distance were $0.66^{(1/d-2)}$, which would take the value of approximately 2.3 for Cumbrian births

Figure 8 West Cumbria, showing 5 km distance annuli around Sellafield and ward boundaries; ward centroids within 25 km of Sellafield are marked +, corresponding to wards included in the study of Wakefield and McElvenny;[1] wards excluded from their study are shaded

very distant from Sellafield. The analysis showed increased risk of stillbirth in particular directions, but no significant effect of distance within any of the directional categories.

The results are consistent with other studies[1,2] investigating stillbirths in relation to distance from Sellafield. Sorahan and Waterhouse[2] looked at stillbirth rates in the county district of Copeland between 1949 and 1981 and found no evidence to suggest an increase in the stillbirth rate around Sellafield following either the Windscale fire in 1957 or radioactive discharges from the plant into the Irish Sea in the 1960s. A study of stillbirths[1] between 1981 and 1991 in wards whose centroids fell within concentric 5 km distance annuli around Sellafield found no evidence of an increase in the stillbirth rate closer to Sellafield. Figure 8 highlights how misclassification of births to distance annuli can occur when the centroid of the ward in which the birth occurred is used to geo-reference the birth.[1] A strength of the present study is the geo-referencing of births by unit postcodes, which on average comprise 24 households, and which resulted in each birth within a 25 km radius of Sellafield being assigned to one of 2961 postcodes compared to one of 32 wards.

Conclusions

The study is estimated to have approximately 80% power, at the 95% confidence level, to detect a relative risk of stillbirth of 1.5 in the 5 km circle around Sellafield. Within these constraints there is no evidence to suggest that proximity to Sellafield increases the risk of stillbirth in the resident population.

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