Public health implications

- Finland, with a mean effective dose of 0.4 mSv among children over the two years after the Chernobyl accident, was one of the countries most heavily affected by the fallout
- For this study, the child population of Finland was divided into fifths on the basis of the radiation dose due to fallout
- No statistically significant effect of fallout from Chernobyl on incidence of childhood leukaemia was detected in the country as a whole, nor in the area with the highest fallout
- Even if there were an effect, its plausible maximum would be within one order of magnitude of that expected on the basis of existing risk estimates
- On the basis of the upper 95% confidence limit of the relative excess risk, an effect of eight cases or more of childhood leukaemia per year per million children in Finland (with approximately 45 cases diagnosed annually) was ruled out

equivalent among Finnish children of radiation from the Chernobyl accident was 0.4 mSv. Using the risk estimates from Hiroshima and Nagasaki,¹⁵ the exposure corresponds to an expected effect of 0.8 extra cases of childhood leukaemia a year among Finnish children. Our point estimate (relative excess risk of 7% per mSv) yields a number of 1.3 cases per year. On the basis of the upper 95% confidence limit (41% relative excess risk per mSv), eight extra cases of childhood leukaemia a year as the true effect can be excluded. In other words, a 17% increase in incidence of childhood leukaemia in Finland was ruled out. We conclude that even if there were an effect that could not be detected in our study, it would be of little public health importance.

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Risk of acute childhood leukaemia in Sweden after the Chernobyl reactor accident

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Abstract

Objective—To evaluate the risk of acute childhood leukaemia in areas of Sweden contaminated after the Chernobyl reactor accident in April 1986.

Design—Population based study of childhood leukaemia diagnosed during 1980-92.

Setting—Coordinates for places of residence of all 1.6 million children aged 0-15 years; aerial mapped areas of Sweden heavily contaminated after the Chernobyl accident.

Subjects—888 children aged 0-15 years with acute leukaemia diagnosed in Sweden during 1980-92, identified with place of birth and residence at diagnosis.

Main outcome measures—Risk of leukaemia in areas contaminated after the Chernobyl accident compared with the rest of Sweden and in the same areas before the accident.

Results—During six and a half years of follow up after the accident the odds ratio for acute leukaemia was 0.9 (95% confidence interval 0.6 to 1.4) in highly contaminated areas ($\geq 10 \text{ kBq/m}^2$) compared with the same areas before the accident. For the subgroup acute lymphoblastic leukaemia in children aged under 5 years at diagnosis the odds ratio was 1.5 (0.8 to 2.6). For all cases diagnosed after May 1986 in highly contaminated areas compared with areas of

low contamination the odds ratio was 0.9 (0.7 to 1.3). For acute lymphoblastic leukaemia in children aged under 5 years at diagnosis the odds ratio was 1.2 (0.8 to 1.9) in highly contaminated areas compared with areas of low contamination. Dose-response analysis showed no correlation between the degree of contamination and the incidence of childhood leukaemia.

Conclusion—There has been no significant increase in the incidence of acute childhood leukaemia in areas of Sweden contaminated after the Chernobyl reactor accident.

Introduction

An explosion at the Chernobyl nuclear power plant on 26 April 1986 released large amounts of radioactive particles for nine days. Areas in the Soviet Union near the plant were the most heavily contaminated. Winds and rain resulted in varying degrees of contamination in different parts of Europe, especially Northern areas. The first cloud moved north west over Poland and Scandinavia. Rainfall in parts of Sweden resulted in heavy deposits of radioactive material. The most important nuclide in the fallout was caesium-137, which has a half life of 30 years. Airborne measurements of nuclide contamination were undertaken by

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the Swedish Geological Company covering the whole of Sweden.¹ Levels equivalent to one tenth of those found in the regions closest to Chernobyl were noted in some areas.

We analysed the geographical distribution of childhood leukaemia in Sweden with regard to the degree of contamination in different areas.

Subjects and methods

All Swedish children aged 0-15 years were marked on a digitised map and narrowed down to place of household on 31 December 1982 and 31 December 1988. This established a background population of 1.6 million children distributed among 1 million data points. All 888 cases of acute leukaemia in children aged 0-15 years and diagnosed during 1980-92 were marked in the same way on the map and served as the case in the study. Part of the population therefore overlapped. Cases, however, did not overlap, as they were identified from the date of diagnosis.

Analyses were performed in two ways. Firstly, children diagnosed during June 1986 to December 1992 in the highly contaminated areas after the accident were compared with children diagnosed during January 1980 to May 1986 in the same areas but before the accident. Secondly, all children with leukaemia diagnosed during June 1986 to December

1992 in Sweden and living in highly contaminated areas were compared with children with leukaemia living in areas of low contamination. The place of birth and residence at diagnosis were known, which allowed analysis of the degree of migration of the cases and also of exposure in utero of children who later developed leukaemia. Of the leukaemia cases, 765 (86.1%) were acute lymphoblastic leukaemia and 123 (13.9%) acute non-lymphoblastic leukaemia.

RADIATION EXPOSURE

The Swedish Geological Company performed detailed measurements during May to October 1986 using an airborne spectrometer to register nuclide γ radiation. ^{134}Cs was chosen as the basic nuclide for estimating deposition and used as an indicator of ^{137}Cs .¹ Based on these recordings, maps were produced indicating different ground levels of ^{137}Cs activity. Levels up to 200 kBq/m² were found. These maps were digitised and used as background data on contamination.

GEOGRAPHICAL INFORMATION SYSTEM

A computerised technique—namely, a geographical information system (ARC/INFO)—was used to analyse the data.² A geographical information system consists of topographical and attribute databases containing spatially referenced data. Information from mono-disciplinary surveys may be efficiently combined and integrated by overlaying databased maps.

All the background population data in different areas, coordinates of the leukaemia cases, and the digitised map of ground levels of ^{137}Cs activity were analysed by a geographical information system. By means of spatial analyses using overlay functions each child was identified with respect to the degree of radioactive exposure.

STATISTICAL ANALYSIS

In the statistical analysis the incidence of leukaemia in areas of low contamination (<10 kBq/m²; A) was compared with the incidence in highly contaminated areas (≥ 10 kBq/m²; B). We defined the odds ratios as odds B/odds A, where odds A=leukaemia divided by the probability of not leukaemia in area A.³ As the risk values in the study were small, the odds ratios were identical with the corresponding relative risk ratios to at least two places of decimals.

A dose-response analysis with logistic explanation regression was used to test the null hypothesis that the risk of disease was independent of radiation dose.⁴ The odds were viewed as a continuously increasing (or decreasing) function (odds (x)) of radiation level x where the analyses were based on grouped exposure levels shown in the figure. In the logistic explanation regression model the natural log of the odds was a linear function of x, giving $\log(\text{odds}(x)) = a + bx$. The parameter of interest was b, which was zero if radiation had no effect on the risk of acquiring leukaemia. The hypothesis $b=0$ could be tested by χ^2 test.

We analysed the data with respect to both place of birth and place of residence at diagnosis. In the first group only children born after the reactor accident were included. As other studies have indicated that children below 5 years of age at diagnosis are most vulnerable to radiation exposure,⁵ we focused our analysis on this subpopulation.

Results

The figure shows a digitised map of the levels of ^{137}Cs activity in different parts of Sweden. The areas most highly contaminated were in a zone from mid-eastern Sweden to the north west.

Table I shows the numbers of cases of acute

Digitised map of ground levels of activity of ^{137}Cs in Sweden, based on airborne measurements during May to October 1986

TABLE I—Cases of acute lymphoblastic leukaemia and acute non-lymphoblastic leukaemia in the two study periods analysed by place of residence at diagnosis and with population data for 1982 and 1988

¹³⁷ Cs (kBq/m ²)	January 1980 to May 1986						June 1986 to December 1992					
	Age 0-15 years			Age 0-5 years			Age 0-15 years			Age 0-5 years		
	No of cases of acute lymphoblastic leukaemia	No of cases of acute non- lymphoblastic leukaemia	Background population 31 December 1982	No of cases of acute lymphoblastic leukaemia	No of cases of acute non- lymphoblastic leukaemia	Background population 31 December 1982	No of cases of acute lymphoblastic leukaemia	No of cases of acute non- lymphoblastic leukaemia	Background population 31 December 1988	No of cases of acute lymphoblastic leukaemia	No of cases of acute non- lymphoblastic leukaemia	Background population 31 December 1988
<10	330	45	1 484 850	185	20	421 592	349	65	1 436 953	179	43	458 786
10-19	22	5	90 248	8	3	26 343	22	3	88 845	16	0	28 983
20-29	5	0	17 953	1	0	4 721	5	0	17 267	1	0	5 408
30-39	5	0	27 043	2	0	7 290	8	1	25 432	6	0	7 559
40-59	7	2	36 839	3	1	10 198	5	1	33 785	3	0	10 777
60-79	3	0	8 578	2	0	2 420	1	0	7 926	1	0	2 307
80-99	2	1	3 027	1	0	796	1	0	2 901	0	0	919
≥100	0	0	199	0	0	67	0	0	232	0	0	79
Total	374	53	1 668 737	202	24	473 427	391	70	1 613 341	206	43	514 818

lymphoblastic leukaemia and acute non-lymphoblastic leukaemia during the two study periods January 1980 to May 1986 (period 1) and June 1986 to December 1992 (period 2). The background populations of children in 1982 and 1988 are also shown. There were more children below 5 years of age in 1988, reflecting the higher birth rates in Sweden during the second half of the decade. One in 10 children lived in areas with ground levels of ¹³⁷Cs activity ≥10 kBq/m² after the accident. In these areas 52 children were diagnosed as having acute leukaemia in period 1 and 47 diagnosed as having acute leukaemia in period 2. Of these, 17 and 27 respectively were cases of acute lymphoblastic leukaemia diagnosed at under 5 years of age (table II).

Table III gives the results of statistical analysis of cases diagnosed in period 2 with respect to place of residence at the time of diagnosis—that is, areas with high levels of contamination (≥10 kBq/m²) compared with areas with low levels of contamination—and age. The estimated odds ratios were all close to 1.0, and none was significant. Likewise, in the logistic regression none of the b parameters was significantly different from zero. For example, the estimated odds ratios at 50 kBq/m² compared with 10 kBq/m² were all close to 1.0 with a range of 0.8 to 1.1.

Geographical migration among leukaemia cases was examined for the whole study period (1980-92). One patient had moved from an area of low contamination to a highly contaminated area between the time of birth and diagnosis. No migration in the opposite direction

occurred. Nine patients moved among different areas with levels of contamination ≥10 kBq/m². The same analysis as in table III, but based on place of residence at birth instead of at diagnosis, gave a similar result—that is, no evident increase in childhood leukaemia in highly contaminated areas (data not shown).

There remained the possibility that there might be an inherent geographical difference in risk function due not to contamination from the Chernobyl reactor accident but to other, unknown factors. We therefore compared the incidence of acute childhood leukaemia in the highly contaminated area after the accident (period 2) with that in the same area before (period 1). The results are shown in table II. No significant odds ratios were identified either for all the cases or for cases diagnosed in children under 5.

Results were substantially the same when cases occurring within two years after the accident were excluded (data not shown). Not one case of acute non-lymphoblastic leukaemia in a child under 5 was diagnosed in highly contaminated areas after the accident (four cases expected). The only tendency was for an increased incidence of acute lymphoblastic leukaemia diagnosed in children under 5 (odds ratio 1.5; 95% confidence interval 0.8 to 2.6). This, however, was not significant. These 27 children were compared with the 179 children with acute lymphoblastic leukaemia diagnosed at under 5 years of age in the rest of Sweden. There were no differences in age, sex, haematological values (white cell count, platelet count, haemoglobin concentration), or immunological markers in blast cells between cases from highly contaminated areas and those from areas of low contamination.

Cytogenetic analyses showed pseudodiploid karyotype in five of 25 cases in contaminated areas compared with 15 of 151 cases in non-contaminated areas. Three of the 25 cases in contaminated areas had a translocation (4; 11) diagnosed in blastic cells compared with one of the 151 cases in the rest of Sweden.

Numbers of acute lymphoblastic leukaemia cases diagnosed in children under 5 in highly contaminated areas after the accident were two during the second half of 1986 and then six, eight, three, three, three, and two respectively in each of the years thereafter. Thus we observed 16 cases within two and a half years after the accident (eight cases expected).

Discussion

The risk of childhood leukaemia after exposure to low dose radiation is uncertain. The consequences of the Chernobyl reactor accident offered a unique opportunity to elucidate the risk. Our study was a detailed analysis of one of the most contaminated areas in Europe. Prerequisites for analysis were detailed registers of population data and data on cases down to

TABLE II—Odds ratios for diagnoses in two age groups in study period 2 compared with study period 1 in areas with ground levels of ¹³⁷Cs activity ≥10 kBq/m² after Chernobyl reactor accident

Age group (years)	No of cases diagnosed during January 1980 to May 1986	No of cases diagnosed during June 1986 to December 1992	Odds ratio (95% confidence interval)
<i>Acute lymphoblastic leukaemia and acute non-lymphoblastic leukaemia</i>			
0-15	52	47	0.9 (0.6 to 1.4)
0-5	21	27	1.1 (0.7 to 2.0)
<i>Acute lymphoblastic leukaemia</i>			
0-15	44	42	1.0 (0.7 to 1.5)
0-5	17	27	1.5 (0.8 to 2.6)

TABLE III—Statistical analysis of cases diagnosed in two age groups in study period 2 in areas with ground levels of ¹³⁷Cs activity <10 kBq/m² compared with areas with ground level of ¹³⁷Cs activity ≥10 kBq/m² after Chernobyl reactor accident

Age group (years)	Odds ratio (95% confidence interval) for areas with ¹³⁷ Cs activity < 10 kBq/m ² v ≥ 10 kBq/m ²	Logistic regression		
		Odds (x)	χ ² Test on b	Odds ratio 50 kBq/m ² v 0 kBq/m ²
<i>Acute lymphoblastic leukaemia and acute non-lymphoblastic leukaemia</i>				
0-15	0.9 (0.7 to 1.3)	e ^{-8.1} 0.0041x	P=0.40	0.8
0-5	1.0 (0.7 to 1.5)	e ^{-7.6} 0.0038x	P=0.57	0.8
<i>Acute non-lymphoblastic leukaemia</i>				
0-15	1.0 (0.7 to 1.4)	e ^{-8.3} 0.0022x	P=0.66	0.9
0-5	1.2 (0.8 to 1.9)	e ^{-7.8} 0.0015x	P=0.82	1.1

Clinical implications

- Low dose radiation as an aetiological factor in childhood leukaemia is controversial
- Fallout after the Chernobyl reactor accident in April 1986 increased exposure to low dose radiation in parts of Sweden
- Use of a geographical information system facilitated detailed study of the effects of fallout after the Chernobyl accident on acute childhood leukaemia in Sweden
- No overall increase in acute childhood leukaemia was detected
- There was a non-significant increase in acute lymphoblastic leukaemia in children under 5

the place of residence. A tool for spatial analysis was also necessary. We used the geographical information system ARC/INFO.

Childhood leukaemia is of special interest because of its short period of latency—estimated to be two to 10 years.^{5,6} The time of exposure to potential environmental aetiological factors is often short. Other studies of the consequences of the Chernobyl accident have found no significant increase in childhood leukaemia in areas contaminated with radioactive fallout.⁷⁻⁹ One study covered several European countries and based results on two and a half years of follow up.⁷ The background data were crude.

The quality of background data is of the utmost importance when studying comparatively rare diseases such as acute childhood leukaemia, as avoiding wrong correlations and not missing potential correlations must be assured. The quality of coordinates for the background population and for the leukaemia cases in this study was the best available in Sweden. The quality of radiation exposure data was also the best available.

We found no significant increase in childhood leukaemia in areas of Sweden with ground levels of ¹³⁷Cs activity ≥ 10 kBq/m². Not one case of acute non-lymphoblastic leukaemia was diagnosed in a child under 5 in highly contaminated areas, when four were expected. The only tendency for an increased odds ratio concerned acute lymphoblastic leukaemia in children under 5. As acute lymphoblastic leukaemia and acute non-lymphoblastic leukaemia are different diseases, probably with a different aetiology, we sug-

gest that future studies should treat them separately.

The numbers of leukaemia cases in our study were fairly small. However, our methods were precise and the period of follow up comparatively long. Among other aspects we studied the migration of cases to the time of diagnosis. Information on place of birth facilitates study of the possible effects of exposure on parental gonads or in utero, or both.¹⁰

During the 30 months after the reactor accident more leukaemia cases occurred in highly contaminated areas than expected. Theoretically, any increase in the incidence of leukaemia should be seen within two to 10 years after exposure. According to conventional risk estimates the expected excess of childhood leukaemia for the study period is less than one case.¹¹ We do not know the expected short term effects (that is, within two to three years after exposure). The increase in cases within the first two and a half years followed by a decrease to expected numbers is inconclusive. We conclude that it was due to chance. However, we suggest that other studies should focus on this aspect.

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A MEMORABLE PATIENT

A lesson once learnt. . . .

I was surgeon in charge of a small tea planters hospital in Darjeeling, north India, some 500 miles from the nearest major hospital in Calcutta. One night a 28 year old Nepali man was brought to me from an outlying district. He was moribund and obviously suffering a massive abdominal bleed, but with no history to indicate its cause.

There was no blood bank nearer than Calcutta. The local so called laboratory was closed, but I knew that my husband was group O so we quickly took a pint of blood from him and ran it rapidly into the patient while the theatre was prepared. A quick incision produced a fountain of blood, which we strained through gauze and put straight back into the patient's veins.

All I could ascertain about the source of the haemorrhage was that it came from the inferoposterior area of the liver. We had no suction apparatus and as soon as I released pressure from the bleeding area blood filled the wound. It was impossible to visualise the source

of the bleeding. It was obviously a losing battle.

My thoughts flashed back 12 years to an occasion when I was assisting Mr Norman Tanner, the world famous gastro-oesophageal surgeon, in St James's Hospital in Balham at a complicated portacaval anastomosis. A jet of blood suddenly shot into the air. Mr Tanner calmly packed the bleeding area with a large gauze pack and closed the wound. Forty eight hours later he removed half the pack and the remainder in another 24 hours. To my astonishment there was no bleeding and the patient went home, seemingly no worse off for the procedure.

I repeated that technique on the young Nepali with similar results. Six years later we met again in Kathmandu, capital of Nepal, by which time he was a prominent politician. He was in excellent health and had never discovered the cause of his emergency illness.—MEG PATTERSON is a consultant in neuroelectric therapy in Roseland, New Jersey