CHAPTER 13

Studies of Pregnancy Outcome Following the Chernobyl Accident

Alfred Korblein

Untere Soeldnersgasse 8, D-90403 Nuremberg, Germany
alfred.koerblein@gmx.de

Perinatal mortality annual data from Germany and Poland show significant increases in 1987, the year following the Chernobyl accident, relative to the long term trend. In an analysis of German monthly perinatal mortality data, peaks of perinatal mortality in the beginning and at the end of 1987 are found. Both peaks are associated with peaks of the caesium burden in pregnant women 7 months earlier (95% CI: 5.5 to 8.5 months). Infant mortality monthly data from Poland exhibit the same pattern. The association with the delayed caesium concentration is highly significant. A combined regression of early neonatal mortality data from Germany and infant mortality data from Poland finds a curvilinear dose response relationship with an estimated power of dose of 2.8 ± 0.8. The perinatal mortality rate in Gomel, the most contaminated region of Belarus, is compared with the rate in the rest of Belarus. The rates do not differ significantly until 1988 but then the rate in Gomel rises and reaches a 30% increased level in the 1990's. This increase can be explained as a late effect of the strontium uptake. In February 1987, a significant 11.4% drop of birth rate is observed in Bavaria which might be explained by an increased rate of spontaneous abortions immediately after Chernobyl when the radiation intensity was highest. The health effects reported here all show a temporal correlation with the radiation exposure from Chernobyl. According to conventional radiobiological knowledge, no teratogenic effects are expected to occur below a threshold dose of about 100 mSv. Even in the most contaminated regions of Germany, however, the extra doses to the foetus were below 1 mSv in the first follow-up year. Therefore the results contradict the widely accepted concept of a threshold dose for radiation damage during foetal development.

1 Background

The observation of pregnancy outcome is a sensitive tool to detect possible adverse health effects on human populations exposed to ionising radiation or other toxic agents. Adverse pregnancy outcomes can be spontaneous abortions, congenital malformations, or perinatal deaths. While perinatal mortality data are available in most countries, there are few registers of congenital malformations, and most registers are incomplete. The European register of congenital malformations EUROCAT covers only about 10% of the European population.

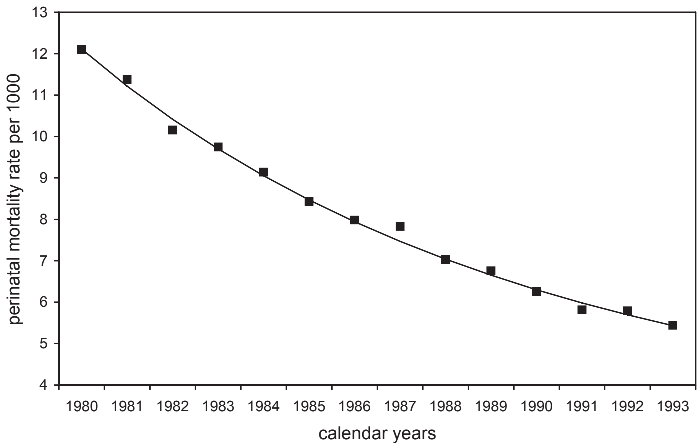
The nuclear accident in Chernobyl on April 26, 1986, was the most severe accident during the civil use of nuclear power. Large parts of Europe were contaminated by the radioactive isotopes of iodine and caesium; strontium and plutonium were also recorded nearer to the Chernobyl site. For radiobiologists and epidemiologists, the Chernobyl accident offered a unique chance of studying the effects of low level ionising radiation on the health of the general population. But the consequences of the Chernobyl disaster are still under debate. The only generally accepted health effect of the Chernobyl accident is a dramatic rise of thyroid cancers in Belarus, Ukraine and parts of the Russian Federation.

Few studies are published in peer reviewed journals on the effects of Chernobyl on perinatal mortality or stillbirth rates. Some of the papers are descriptive reports; precise quantitative results (p-values and confidence intervals) are rather rare. In most cases negative findings are reported, as a rule without mentioning the statistical power of the studies.

In Finland, no significant increase of malformations rates or perinatal deaths was found [1]. In West Germany, an upward deviation from an exponentially falling trend of early neonatal mortality was reported after Chernobyl in Bavaria and Baden-Wuerttemberg, the German Federal States with the highest radiation exposure [2]. But the result depended on the extrapolation model used and was suspected to be an artefact [3]. In Norway, there was an increase of spontaneous abortions for pregnancies conceived during the first 3 months after the Chernobyl accident [4]. Likewise, a 7.2% decrease of birth rate in February 1987 was found in Italy [5]. In Hungary, no increase of congenital abnormalities was observed after the Chernobyl accident, but again, the rate of live births decreased 9 months after May and June 1986 [6]. In the English counties of Cumbria, Clwyd and Gwynedd, where there was heavy rainfall during the passage of the radioactive cloud, no rise of perinatal mortality rates relative to the rest of the country was observed [7]. In a review article about congenital anomalies and other reproductive outcomes the author concludes that there is no consistent evidence of a detrimental physical effect of the Chernobyl accident on congenital anomalies [8]. An increase in unfavourable pregnancy outcome, including a rise of perinatal mortality, was observed in two heavily polluted districts near the Chernobyl reactor site [9]. In Sweden, no change in the rate of spontaneous abortions or congenital malformations occurred in pregnancies exposed at the time of the accident [10]. In Kiev, no pronounced change of perinatal mortality rates was observed after Chernobyl [11].

An increase of developmental abnormalties was found in 5-12 week old human embryos in Belarus after Chernobyl [12]. Also in Belarus, neonates born in heavily contaminated areas were apparently at risk for developing anaemia, congenital malformations and perinatal death [13]. In a review article Goldman states that no significant adverse medical effects other than thyroid cancers in children have been reported in the populations affected by the Chernobyl accident [14]. In Germany, malformation rates [15] and perinatal mortality rates [16] after Chernobyl in the higher polluted southern part of the State of Bavaria were compared to the rates in the less polluted northern part of Bavaria. No significant differences were found. The statistical power of the study, however, was rather weak [17]. A trend analysis of German monthly perinatal mortality rates found peaks that were associated with calculated peaks of caesium concentration in the bodies of pregnant women 7 months earlier [18]. A persistent increase of stillbirth rates after Chernobyl was reported for some eastern European countries outside the former Soviet Union (Sweden, Poland, Hungary, Greece), while no increase was found in central and western European countries [19]. In the State of Bavaria, excess stillbirth rates in 1987 correlated with the level of fallout [20]. A similar study found no correlation between fallout level and stillbirth rate in Finland [21]. In Belarus, perinatal mortality rates in the region of Gomel, which experienced the highest fallout from Chernobyl, were increased in the 1990's relative to the rates in the remainder of the country. The increase was associated with the calculated strontium concentration in pregnant women [22].

Figure 1: Perinatal mortality rates in Germany and long-term trend.



The only official German study of perinatal mortality rates was conducted by the Federal Office of Radiation Protection (Bundesamt für Strahlenschutz) [16]. Data from Bavaria were chosen for this study because Bavaria is the German state that experienced the highest fallout from Chernobyl. The population weighted caesium soil contamination was about 4-times higher in southern Bavaria than in northern Bavaria. A possible radiation effect should have changed the ratio of perinatal mortality in southern to northern Bavaria after Chernobyl. However, the authors did not find any change in this ratio after Chernobyl. This was perceived as evidence that there were no radiation effects from Chernobyl in Germany. It can be shown, however, that the power of the study was too small to detect differences in perinatal mortality rates below 30%. To find small effects, larger populations are needed.

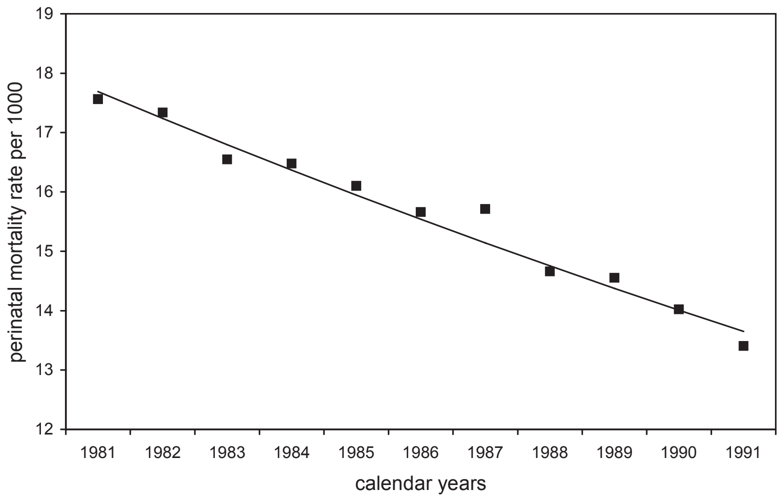
This article is an overview of my studies about the effects of the Chernobyl fallout on pregnancy outcome in Germany, Austria, Poland, Belarus, and Ukraine. To maximise the statistical power of the studies, I included all available German data (80 million population) rather than limiting the investigation to one German region (Bavaria, 11 million population) as in [16]. With a trend analysis, the effects of short time perturbations are investigated on the same population, so any confounding factors can be practically excluded. The calculation of the long-term trend will be more precise as more data before and after 1986, the year of the Chernobyl accident, are available.

2 Data

Perinatal mortality is the number of stillbirths plus early neonatal deaths (0-6 days), divided by the number of live births plus stillbirths. Since in Germany the criteria for stillbirth changed in 1980 and 1994, the study period was restricted to 1980-1993. In 1980, the criterion for stillbirth changed from a body length of 35 cm to a birth weight of 1000 grams, which again was changed to 500 grams in 1994.

German monthly perinatal mortality data, 1980-1993, were obtained from the German Statistical Office (Statistisches Bundesamt). Monthly infant mortality data from Poland, 1985-1990, were supplied by the Institute of Mother and Child in

Figure 2: Perinatal mortality rates in Poland and long-term trend.



Warsaw. Perinatal mortality data and maternal age distributions from Belarus were provided by the Statistical Department of the Belarus Ministry of Health in Minsk.
The caesium-137 soil contamination ranged from 2-3 kBq/m² in northern Germany to over 50 kBq/m² in southern Germany. Measured caesium concentrations in cows' milk in Munich, Germany, from May 1986 to December 1988, were provided by the state supported Society for Environment and Health (Gesellschaft für Umwelt und Gesundheit, GSF*)*.

3 Annual data

Model
Perinatal mortality data are binary data, therefore the appropriate trend model is a logistic regression model. A flexible form of the time dependency with a linear and a quadratic term is used to describe the undisturbed long-term trend of the data. To test a possible influence of the Chernobyl radiation on perinatal mortality in 1987, a dummy variable d_{87} is used with $d_{87}=0$ in all years except 1987 where $d_{87}=1$. The model has the following form:

(3.1) $E(Y(t)) = 1/(1+1/\exp(\beta_1 + \beta_2 \cdot t + \beta_3 \cdot t^2 + \beta_4 \cdot d_{87}))$.
Here $E(Y(t))$ is the estimated perinatal mortality rate, parameter β_1 is the intercept, β_2 and β_3 estimate the linear and quadratic temporal trends, and β_4 estimates the possible increase in 1987. A one-sided t-test is used to determine the significance of the excess perinatal mortality rate in 1987 (hypothesis H_0: $\beta_4 \leq 0$).

Results
Germany: A regression yields a good fit to German perinatal mortality data. The quadratic term in the time dependency is highly significant (p=0.002, F-test). In 1987, there is a significant 4.9% increase relative to the trend of all other years (p=0.0088). The excess rate in 1987 is 0.36 per 1000 births that translates to 317 excess cases (95% CI: 67-578).

The increase of perinatal mortality in 1987 is essentially driven by a 7.4% increase of early neonatal mortality rate (p=0.0035; 95% CI: 2.1% to 13.0%); the 2.9% increase of stillbirth rate is not significant (p=0.100).

Other countries: In the trend analysis of perinatal mortality rates from Poland, 1981-1991, a linear logistic regression model is used. Again, the excess perinatal mortality rate in 1987 is significant ($p=0.0074$). The excess rate is 0.57 per 1,000 births that translates to 354 excess cases (95% CI: 89-626). About 75% of the excess perinatal deaths in 1987 are early neonatal deaths.

A combined regression for Germany and Poland, with individual trend parameters but a common parameter for the relative increase in 1987, yields a highly significant 4.2% rise ($p=0.0003$).

The trends of perinatal mortality rates in Germany and in Poland are shown in Figure 1 and Figure 2. The deviations from the trend, in units of standard deviations (standardised residuals), are displayed in Figure 3.

In England and Wales no increase of perinatal mortality rates is observed in 1987 relative to the trend of the data 1981-1992 (see Figure 4). The excess perinatal mortality rates in 1987 obtained from the regressions are listed in the following Table. The increase is greater in Poland than in Germany, and greater in East Germany (former GDR) than in West Germany.

Excess perinatal mortality rates 1987

data set	excess rate	% increase	excess cases	p-value*
Poland	0.572	3.8%	354	0.0074
Germany	0.363	4.9%	317	0.0088
West Germany	0.247	3.5%	159	0.0733
East Germany	0.623	7.2%	141	0.0279

** one-sided t-test*

4 Monthly data

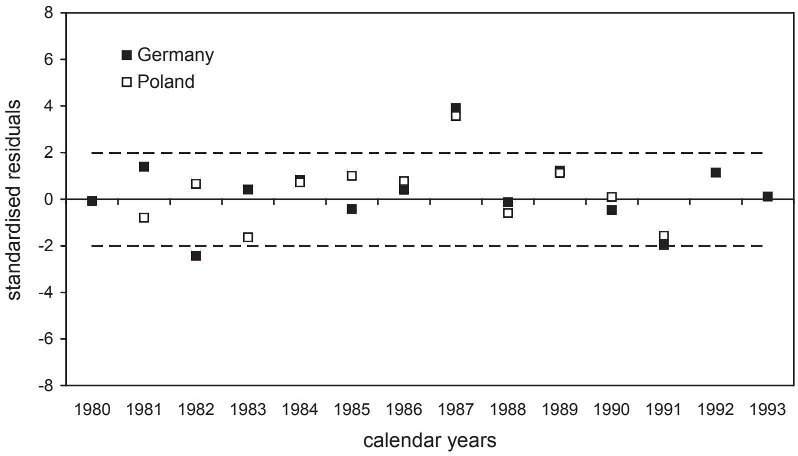
Model

A model for the trend of monthly data has to allow for seasonal variations of perinatal mortality rates. Two periodic terms with periods of 12 and 6 months are therefore added to model 3.1. Four additional parameters are needed, two for the amplitudes ($\beta 4$, $\beta 6$) and two for the phase shifts ($\beta 5$, $\beta 7$):

(4.1) $$E(Y(t)) = 1/(1+1/\exp(\beta 1 + \beta 2 \cdot t + \beta 3 \cdot t^2 + \beta 4 \cdot \cos(2\pi \cdot (t-\beta 5)) + \beta 6 \cdot \cos(2\pi \cdot (2t-\beta 7))))$$

The caesium concentration in cows' milk is used as a proxy for the total internal radiation exposure from caesium, essentially because data of caesium contamination in cows' milk were available. The caesium concentration in cow milk was measured nearly every day at the Munich based GSF-Institute, from the beginning of May 1986 until the end of 1988. In the first year following Chernobyl, the internal exposure of the German population exceeded the external caesium exposure [23]. Milk produced in higher contaminated southern Bavaria was distributed and consumed throughout West Germany.

Figure 3: Deviations between observed and expected rates in units of standard deviations (standardised residuals) in Germany (black squares) and Poland (white squares). The broken lines show the range of 2 standard deviations (2σ-range).



The calculation of the caesium concentration in pregnant women is based on the assumption of a constant daily milk consumption and a somewhat shortened biological half-life of caesium of 70 days during pregnancy. The caesium burden increases with caesium uptake and decreases with caesium excretion. Figure 5 shows the measured caesium concentration in milk (dots) and the calculated caesium burden in pregnant women (solid line).

The regression model with the caesium term has the following form:

(4.2) $E(Y(t)) = 1/(1+1/\exp(\beta1 + \beta2 \cdot t + \beta3 \cdot t^2 + \beta4 \cdot \cos(2\pi \cdot (t-\beta5)) + \beta6 \cdot \cos(2\pi \cdot (2t-\beta7)) + \beta8 \cdot (cs(t-\beta10))\verb|^|\beta9))$

Parameter β8 estimates the size of the caesium effect, β10 is the time-lag between caesium concentration cs(t) and perinatal mortality, and β9 is the power of dose which allows for a curvilinear dose-response relationship.

To test the significance of the caesium term, the weighted sum of squares resulting from a regression with the full model (4.2) is compared with the sum of squares obtained from a regression without the caesium term (model 4.1). The F-test is applied where the F-value is defined by

$F = ((\chi^2 0-\chi^2 1)/(df0-df1))/(\chi^2 1/df1)$.

Here $\chi^2 0$ and $\chi^2 1$ denote the weighted sum of squares under the null hypothesis and under the full model, respectively; df0 and df1 are the corresponding degrees of freedom. Here df0-df1 equals the number of parameters to be tested. The expression $\chi^2 1/df1$ in the denominator is the so called overdispersion factor. For a detailed description of the methods see [18].

Perinatal mortality in Germany

German monthly perinatal mortality rates and the regression line are displayed in Figure 6. Figure 7 shows the deviations of the observed rates from the calculated undisturbed trend (standardised residuals) and the three-month moving average.

Figure 4: Perinatal mortality rates in England and Wales and long-term trend.

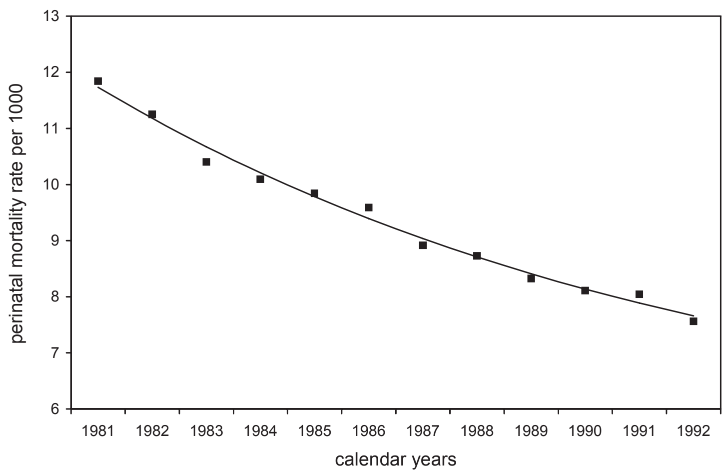
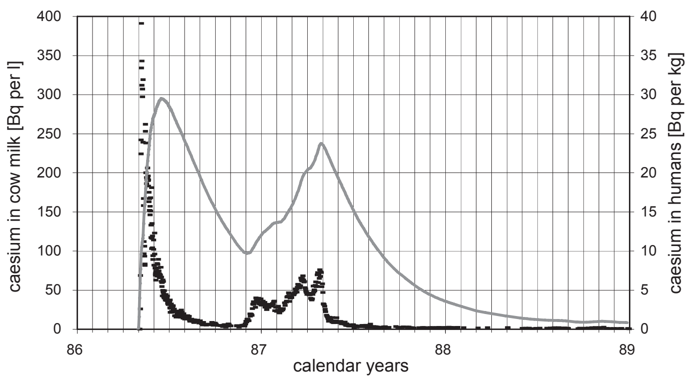


Figure 5: Caesium concentration in cows' milk (short dashes) and in pregnant women (solid line), calculated with a constant daily consumption of cow milk and a biological half life of 70 days.

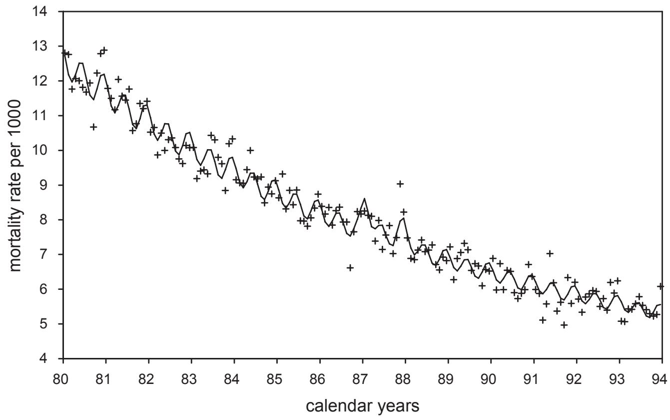


There are significant peaks of perinatal mortality in the beginning and at the end of 1987.

A regression without the caesium term (model 4.1) yields a weighted sum of squares of 221.6 (df=161). Regressions with model 4.2 are then performed with different time-lags β10. The best fit with a sum of squares of 204.5 (df=158) is obtained for a time-lag of 7 months. The corresponding F-test is significant (p=0.0053).

In Figure 8, the profile sum of squares is plotted as a function of the time-lag. The broken line gives an estimate of the 95% confidence interval from 5.5 to 8.5 months based on the F-test.

Figure 6: Monthly perinatal mortality rates in Germany and regression line with seasonal variations.



Infant mortality in Poland

For Poland, monthly data were obtained only for infant mortality (death within the first year of life) and for a relatively short period from 1985 to 1990.

Again, regressions without and with the caesium term are performed, using a time-lag of 7 months as found in the German perinatal mortality data. The corresponding sums of squares are $\chi^2 = 126.8$ (df=65) and $\chi^2 = 99.1$ (df=63). The corresponding F-test is highly significant (p=0.0004, F-test). For time-lags of both 8 and 6 months, the sums of squares are greater than for 7 months. Thus, like in the German data, 7 months is the best estimate for the time-lag. Figure 9 shows the trend of the data and the regression line; Figure 10 displays the deviations of the observed data from the expected trend (standardised residuals).

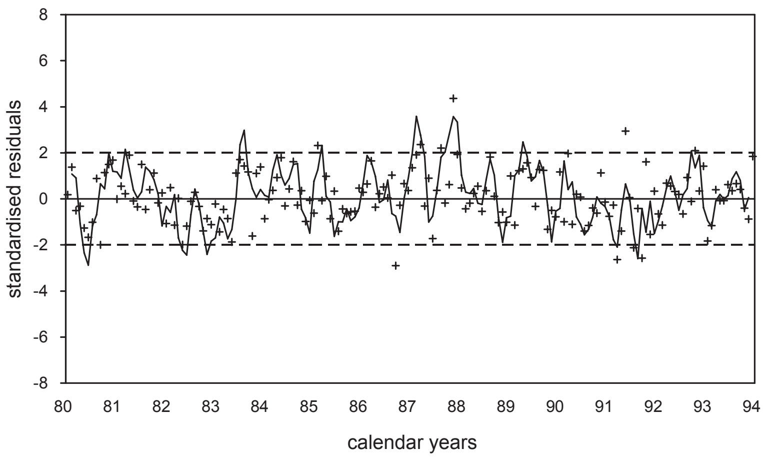
Combined regression

For a comparison of the effect size in Poland and Germany, early neonatal mortality data from Germany were used because perinatal mortality also includes stillbirths. More than 50% of infant deaths in the first year of life actually occur within the first 7 days (early neonatal deaths). To increase the precision of the parameter estimates, a combined regression with individual parameters for the long-term trend and common parameters for the seasonal components and the caesium term is performed.

The sum of squares resulting from the combined regressiom is 356.8 (df=230) without and 310.5 (df=228) the caesium term. The corresponding F-test is highly significant ($p<0.0001$). For time-lags of 6 as well as 8 months, the weighted sums of squares are significantly greater than for 7 months (319.0 and 337.8, respectively).

The best estimate of the power of dose is $\beta 12 = 2.8 \pm 0.8$. With a linear dose response model, i.e. $\beta 12=1$, the sum of squares increases significantly to 321.3 (df=229). The corresponding F-test yields p=0.0052, i.e., the dose dependency is curvilinear.

Figure 7: Deviations of monthly perinatal mortality rates in Germany from the undisturbed trend of the data (standardised residuals). The solid line is the three-month moving average, the broken lines show the 2σ-range.



5 Belarus

The region (oblast) of Gomel was the area with highest fallout in Belarus. The strontium soil contamination in parts of Gomel oblast outside the 30-km exclusion zone exceeded 37,000 Bq/m² in 1986 (see Figure 11) whereas in Munich little strontium was determined in the Chernobyl fallout (210 Bq/m² Sr-90 compared to about 20,000 Bq/m² Cs-137, May 1986),

The trend of perinatal mortality rates, 1985-1998, in the oblasts of Gomel, Minsk-City, and in Belarus minus Gomel and Minsk-City, are displayed in Figure 12. In 1994 there is a 20% increase of perinatal mortality in all three data sets which is the consequence of a definition change for stillbirth.

Perinatal mortality data from the City of Minsk do not conform with the data in the rest of Belarus. The rates from Minsk-City are consistently higher than in the rest of Belarus until after 1995 when they suddenly drop by 50%. No such decrease occurs in the other regions of Belarus, i.e. the peculiarity in the City of Minsk, the capital of Belarus, is not likely to have biological reasons. Therefore the data for the City of Minsk are omitted when perinatal mortality rates in Gomel oblast (study area) are compared to the rates in the rest of Belarus (control area).

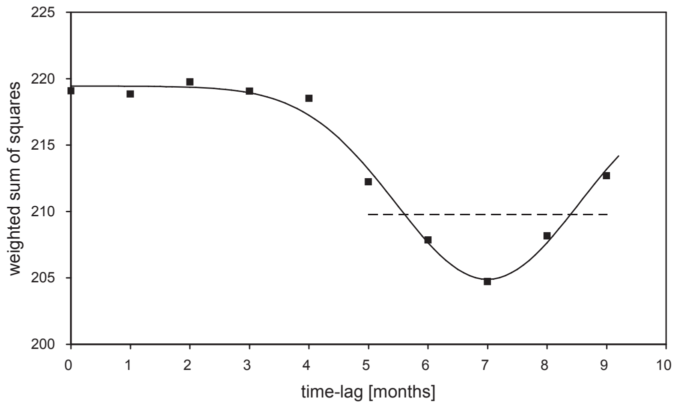
A trend analysis of perinatal mortality data is problematic for two reasons. First – as in most European countries - the definition of stillbirth was changed at the end of 1993. Second, possible socio-economic problems after the break-up of the Soviet Union in 1991 might have had an influence on the trend of perinatal mortality rates. Assuming that these influences acted equally in the study and the control region, a possible effect of radiation exposure should be found in the ratio of perinatal mortality rates in Gomel oblast to the rates in the control area.

Method

The ratio of perinatal mortality rate p1 in Gomel to the rate p0 in the control area can be expressed by the odds ratio (OR) which is defined by

OR = (p1/(1-p1)) / (p0/(1-p0)).

Figure 8: Sums of squares as a function of the time-lag between caesium concentration in pregnant women and perinatal mortality in Germany (profile likelihood). The broken line indicates the 95% confidence interval for the time-lag.

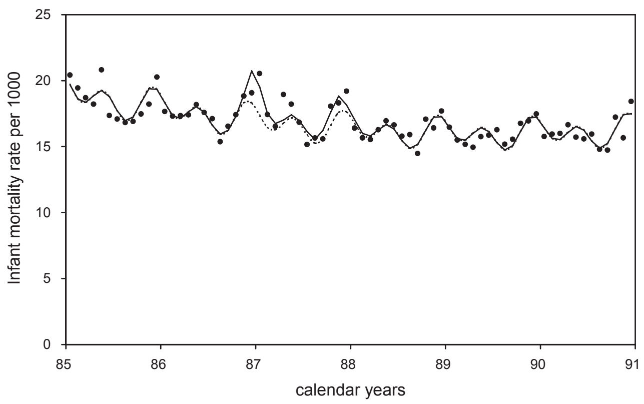


A weighted regression of the logarithms of the odds ratios is performed with the model

(5.1) $\ln(OR) = \ln(1 + \beta 0 + \beta 1 \cdot d87 + \beta 2 \cdot sr(t))$

where parameter β0 allows for a difference in the base line perinatal mortality rates in the study and the control area, β1 estimates a possible caesium effect in 1987 (dummy variable d87) and β2 estimates the possible effect of strontium on the data.
The expression sr(t) is the average strontium concentration in pregnant women calculated under the assumption that strontium is mainly incorporated at the end of the period of menarche, the time of maximum bone growth, at about age 14 [25].

Figure 9: Monthly infant mortality rates in Poland from 1985 to 1990 and regression line. The dotted line is the undisturbed long-term trend.



For a given year following Chernobyl, the average strontium concentration is approximated by the percentage of pregnant women who were 14 years old in 1986, i.e., who were born in 1972. This percentage follows from the maternal age distribution. In Belarus, maternal age distributions were only available in 5 year strata. The shaded area in Figure 13 is the average age distribution in Belarus for 1992-1996. To get approximated annual values, a superposition of two lognormal distributions was used to fit the step function (solid line in Figure 13).

Second, the strontium excretion from the body must be considered in the calculation of sr(t). According to the ICRP Publication 67 [26], the strontium excretion cannot be described by a simple exponential decrease, but is composed of a fast and a slow component. Thus, the strontium term sr(t) in year t after Chernobyl has the form

$sr(t) \sim F(t-1972)\cdot(A1\cdot\exp(-\ln(2)\cdot(t-1986)/T1)+A2\cdot\exp(-\ln(2)\cdot(t-1986)/T2))$

where F(t-1972) is the fraction of pregnant women born in 1972. T1=2.4 years and T2=13.7 years are effective half-lives of strontium in the female body. The constants A1, A2 and the half-lives T1, T2 were determined from a regression of tabulated values given in [27].

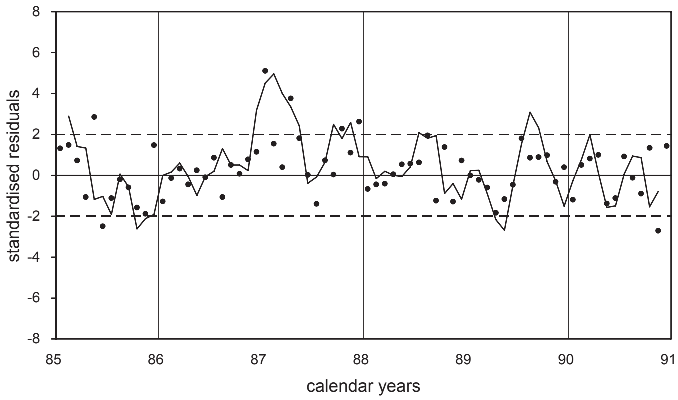
For the regression the data are population weighted with weights

(5.2) $\sigma^2 = 1/n1 + 1/(N1-n1) + 1/n0 + 1/(N0-n0)$

where n1 and n0 are the number of perinatal deaths in the study(1) and control(0) area and N1, N0 the corresponding numbers of live births plus stillbirths.

To test the significance of the parameters, two-sided t-test are applied (H0: β2=0, β3=0).

Figure 10: Deviations of observed infant mortality rates from Poland (dots) from the undisturbed trend (standardised residuals). The solid line is the three-month moving average, the broken lines show the 2σ-range.



Results

To determine the age of maximum strontium uptake from the data, regressions with strontium terms for maximum strontium uptake at age 13, 14, and 15 are performed. The results for the sums of squares are 9.7, 7.3 and 9.9, respectively. Thus the strontium term with an age of 14 years for maximum strontium uptake fits the data best.

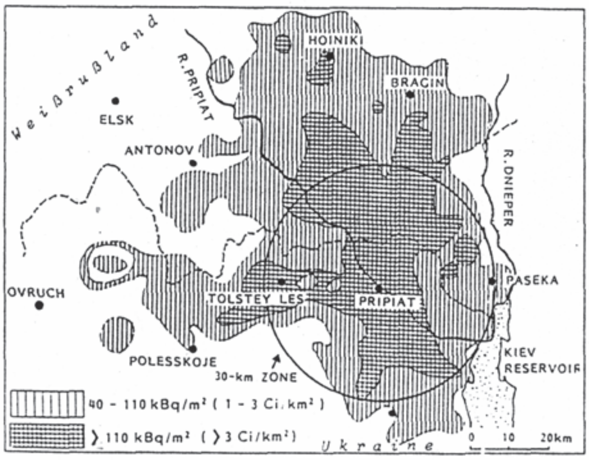
The regression yields β0 = 0.022 ± 0.027, i.e., there is no appreciable difference in perinatal mortality rates between study and control area before Chernobyl. Also, the increase in 1987 is not significant (β1=0.055 ± 0.060).

Not only constant β2 but also the age of maximum strontium uptake was estimated from the data therefore an F-test with two degrees of freedom is applied to determine the significance of the strontium effect. The sum of squares is 29.7 (df=12) without and 7.3 (df=10) with the strontium term. The corresponding F-test is significant (p=0.0028).

Figure 14 shows the observed (dots) and expected odds ratios (solid line) resulting from a regression with β0=0 (see equation 5.1). In the mid 1990's the odds ratios are about

1.3, i.e., perinatal mortality rates in Gomel are 30% higher than in the control area. The excess perinatal mortality rates in Gomel translate to 431 excess perinatal deaths, 1987-1998.

Figure 11: Strontium-90 soil contamination near the Chernobyl reactor site (from German journal Atomwirtschaft, March 1991). The hatched areas indicate strontium concentrations greater than 1 Ci/km² (37 kBq/m²) and 3 Ci/km² (111 kBq/m²), respectively. The circle is the 30-km evacuation zone.



6 Spontaneous abortions in Bavaria

The most sensitive phase in embryonic development is before the first cell division, i.e., during the first hours after fertilisation. In this period an all or nothing rule holds, i.e., the fertilised egg either survives without damage or is aborted. A possible increase of spontaneous abortions will lead to a decrease of live births 9 months after exposure.

Bavaria was the German region with highest fallout. Figure 15 shows continuous measurements of the activity in air 1 meter above ground in the Munich based GSF Institute. Immediately after the Chernobyl accident the activity rose from 8 μR/h to about 110 μR/h. The number of live births plus stillbirths dropped significantly ($p=0.0030$) by 11.4% relative to the long-term trend in February 1987, nine months after May 1986. The decrease is more pronounced in southern Bavaria (-13,4%, $p=0.0005$) than in northern Bavaria (-8.7%, $p=0.0370$) and is limited to a single month. In March 1987, the number of births returned to the expected level. Figure 16 shows the deviations of the monthly number of live births plus stillbirths in southern Bavaria from the trend of the data, 1984-1989. The estimated number of missing births in Bavaria in February 1987 is 1154. There might have been fewer planned conceptions after the Chernobyl accident, but it does not seem plausible that the fear of an adverse pregnancy outcome was limited to May 1986.

Figure 12: Perinatal mortality rates in Gomel, Minsk-City, and Belarus minus Gomel and Minsk-City. The offset in 1994 results from a change in the definition of stillbirths.

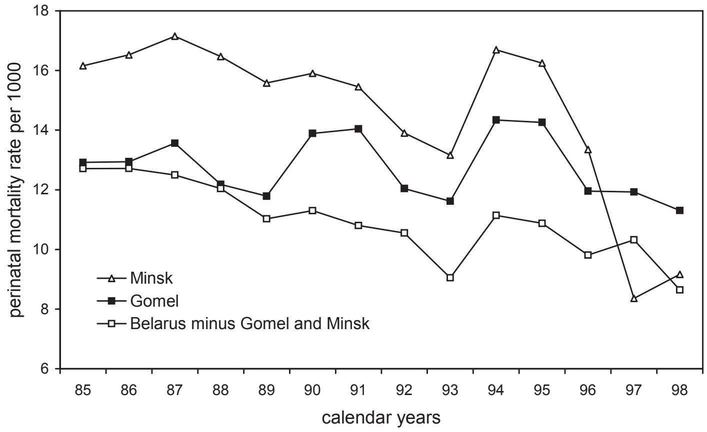


Figure 13*: Maternal age distribution in Belarus, averaged for 1992-1996, and interpolation curve using two superimposed lognormal distributions.*

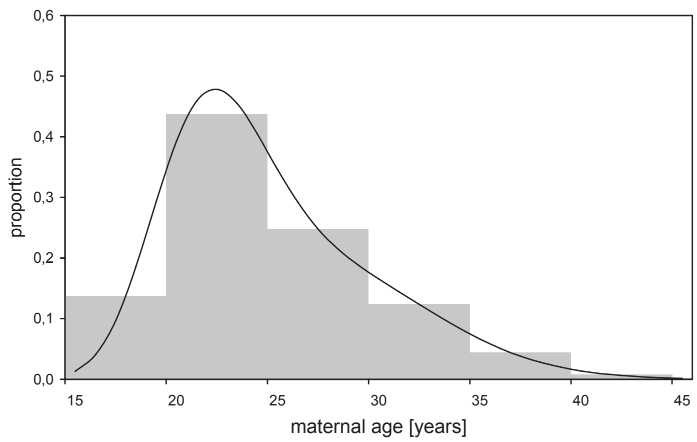


Figure 14: Odds ratios of perinatal mortality in Gomel vs. Belarus minus Gomel and Minsk-City, and regression line.

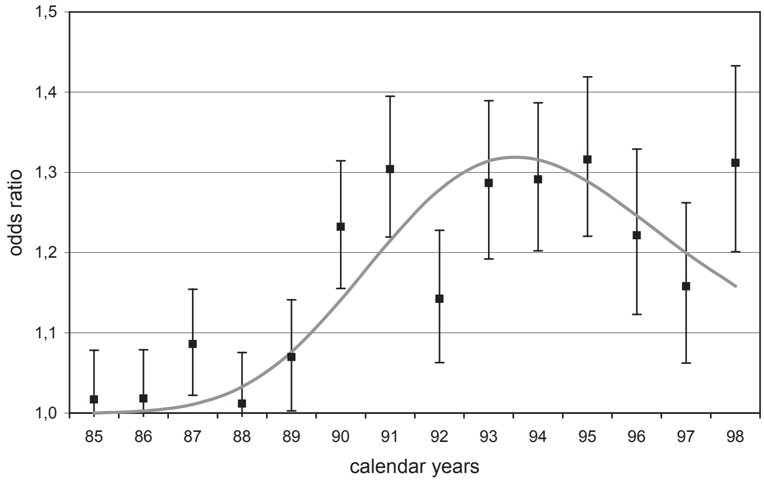


Figure 15: Gamma dose rate in the air during May 1986 in Munich, Germany. In the first days of May it reached about 110 µR/h, more than 10-times the normal level of 8 µR/h.

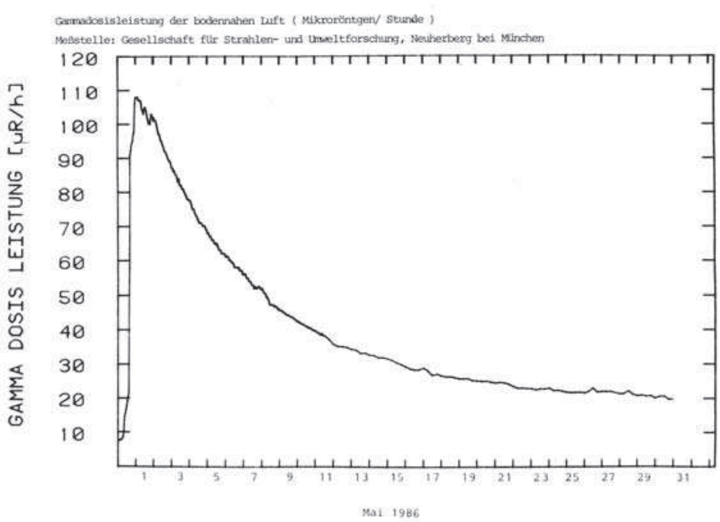
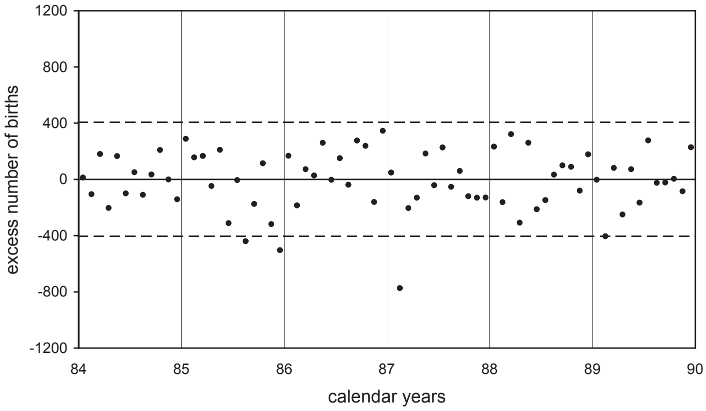


Figure 16: Deviations of the monthly number of live births plus stillbirths from the long-term trend in southern Bavaria. The broken lines indicate the 2σ-range.



7 Discussion

A trend analysis finds significant increases of perinatal mortality in Germany and Poland in 1987, the year following the Chernobyl accident. The monthly data exhibit a significant association between perinatal mortality and the delayed caesium concentration in pregnant women. In Poland, which experienced a higher average fallout from Chernobyl than Germany, the increase of perinatal mortality in 1987, as well as the caesium effect on monthly infant mortality data, is greater than in Germany. No increase in 1987 is found in perinatal mortality data from England and Wales.

In the region of Gomel, Belarus, a significant association of perinatal mortality with the calculated strontium burden in pregnant women is found. The method used to calculate the strontium burden had already been successfully used in a trend analysis of German perinatal mortality after the atmospheric nuclear weapons tests between 1952 and 1963 [28].

In Bavaria, a significant drop in birth rate is observed in February 1987, nine months after the Chernobyl accident, which might well be the consequence of more spontaneous abortions. Similar decreases in birth rate were observed in several other European countries [4, 5, 6].

The findings provide evidence of adverse radiation effects to the foetus in the first trimester of pregnancy and challenge the widely accepted concept of a threshold dose for teratogenic effects. The foetus seems to be much more vulnerable to ionising radiation than generally believed. The form of the dose response relationship, however, is not linear.

The results for Belarus and Ukraine cannot be understood with the present dose factor for strontium. The doses from strontium in the contaminated regions as given in [29] were less than 5% of the doses from caesium but the strontium effect on perinatal mortality exceeded the caesium effect by at least a factor of 10.

The results should be interpreted with caution since they are based on aggregated data. But as long as there is no other way to study small radiation effects in human populations, the findings should not be dismissed for lack of an ultimate proof of causation.

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