Perinatal Mortality in West Germany Following Atmospheric Nuclear Weapons Tests

ALFRED KÖRBLEIN
Munich Environmental Institute
Munich, Germany

ABSTRACT. Using trend analysis, the author sought a possible association between perinatal mortality rates in West Germany, 1955–1993, and the fallout from atmospheric nuclear weapons testing in the years 1952–1993. The regression model used a continuously falling trend and a superimposed extra term that reflects the average strontium content in pregnant women. Mortality rates show an upward deviation that peaked in 1970. The model attributes more than 100,000 excess perinatal deaths to strontium in the fallout. The dose-response curve is curvilinear with a power of dose of 1.81 ± 0.23. In addition, using a combined regression model, the author analyzed the two data subsets of perinatal mortality (i.e., stillbirth rate and early neonatal mortality). The strontium effect is 3.4 times greater on early infant deaths than on stillbirths. According to the prevailing wisdom, the fetus is protected against damage from ionizing radiation by a threshold dose of 50–200 mSv, but the doses from strontium in the fallout were well below 1 mSv/yr in Germany. The results reported here seem to contradict the existence of a threshold dose for perinatal mortality at low doses.

<Key words: bomb tests, dose response, fallout, perinatal mortality, strontium, trend analysis>

ATMOSPHERIC WEAPONS TESTS in the 1950s and 1960s caused the most radioactive pollution globally in the history of nuclear technology. The cumulative explosive power of the tests corresponded to 550 megatons 2,4,6-trinitrotoluene (TNT), which is equivalent to 40,000 atomic bombs of the type that was dropped on Hiroshima at the end of World War II. During the 1960s in the northern hemisphere, the level of strontium-90 in contaminated soil was about 1,700 Bq/m^2, and the level of cesium-137 was 2,500 Bq/m^2. The collective dose to the world population was estimated at 30 million PersonSievert (PersSv), which can be compared with 600,000 PersSv from the Chernobyl accident in 1986.[1]

Sternglass and colleagues[2,3] were the first to propose an association between infant mortality rates in the United States and the fallout from atmospheric nuclear bomb tests. The extrapolated trend of the data in the years 1935–1950 was compared with the observed data in the years following the bomb tests. Their conclusions were rejected by several critics.[4–6] Similar effects were found in first-day neonatal mortality rates in England and the United States, from 1935 to 1987.[7] From the early 1950s until the end of the 1970s the data exhibit a remarkable rise and fall relative to a continuously falling trend in the years before 1950. The number of excess deaths was estimated at 195,000 in the United States and 37,000 in England and Wales. A parallel increase was detected in stillbirth rates. As a possible cause of this loss of life, the exposure to strontium-90 from atmospheric nuclear weapons testing has been discussed.[7]

In West Germany, starting at the end of the 1950s perinatal mortality rates deviated from a continuously falling trend. The objective of this study was to determine whether there is an association between the observed excess perinatal mortality rates in Germany in the 1960s and 1970s and the average strontium content in pregnant women.

Materials and Method

Data. Perinatal mortality is defined as the combined numbers of stillbirths and early infant deaths (0–6 d after birth), divided by the combined numbers of live births and stillbirths. No data of early infant deaths were available in West Germany before 1955. In 1994 the definition of *stillbirth* changed from a birth weight of 1,000 g to 500 g. Annual numbers of live births, stillbirths, and early infant deaths during the years 1955–1993 (see Appendix) were obtained from the German Federal Statistical Office (*Statistisches Bundesamt*). Annual maternal age distribution data from 1955 through 1993 were also provided by the German Federal Statistical Office.

Strontium concentration data in the fallout from atmospheric bomb tests from 1958 to 1981 were obtained from the German Radiation Protection Office (*Bundesamt für Strahlenschutz*).

Regression model. The trend of perinatal mortality rates $\hat{Y}(t)$ in year t is modeled as the sum of a monotonously falling trend plus an extra term $Sr(t)$, which relates the excess perinatal mortality with the average strontium concentration in pregnant women:

$$\hat{Y}(t) = c_1 + (1 - c_1) / [1 + 1 / \exp(c_2 + c_3 t)] + Sr(t) \quad (1)$$

For the long-term trend, a modified logistic regression model with a natural lower limit of perinatal mortality, trend parameters c_2 and c_3, and a natural lower limit (parameter c_1) of perinatal mortality is used. Time t is calendar year minus 1955 (e.g., $t = 0$ is 1955). The method for calculating the strontium term $Sr(t)$ is presented below.

Strontium replaces calcium in the human body. The maximum uptake of strontium occurs during menarche, at about age 14.[8] A first simplifying assumption is that strontium uptake occurs only at age 14.

A possible detrimental effect of strontium on perinatal mortality will manifest in later years when a woman gives birth. The strontium concentration in pregnant women in a certain year t, resulting from the fallout in year k, depends on the amount of fallout in year k and on the fraction of mothers who were 14 yr old in year k (with $k <$ t). This fraction follows from the maternal age distribution. The average strontium concentration in mothers in a given year t is the sum of the contributions from all fallout years k preceding t (i.e., $k < t$).

Second, strontium excretion from the human body has to be taken into account. According to ICRP 67,[9] strontium excretion is not determined by a single effective half-life but is composed of a fast and a slow fraction with half-lives, 2.4 and 13.7 yr, respectively. Thus, the average strontium concentration $conc(t, k)$ in pregnant women in year t resulting from the fallout in year k has the following form:

$$\begin{aligned} conc(t, k) = {} & A(k) \cdot F(t, t - k + 14) \\ & \cdot \{0.135 \cdot \exp[-\ln(2) \cdot (t - k)/2.42] \\ & + 0.099 \cdot \exp[-\ln(2) \cdot (t - k)/13.65]\} \quad (2) \end{aligned}$$

$A(k)$ is the amount of strontium-90 in the fallout in year k, $F(t, t - k + 14)$ is the fraction of mothers age $t - k + 14$ following from the maternal age distribution in year t. The expression with the two exponentials accounts for the strontium excretion; the constants were determined by a regression to tabulated numeric values given in ICRP 67.[9]

Because the form of the dose-response relationship is not known, a flexible model is used to relate the excess perinatal mortality $Sr(t)$ to the strontium content in pregnant women:

$$Sr(t) = c_4 \cdot \Sigma_{k<t}[conc(t, k)\wedge c_5] \quad (3)$$

where the sum is overall $k < t$. Parameter c_4 is a proportionality factor, and c_5 is the power of dose, which allows for a curvilinear dose response relationship. To obtain the final form of the regression model, $Sr(t)$ in equation 1 is replaced by the right side of equation 3:

$$\begin{aligned} \hat{Y}(t) = {} & c_1 + (1 - c_1)/[1 + 1/\exp(c_2 + c_3 \cdot t)] \\ & + c_4 \cdot \Sigma_{k<t}[conc(t, k)\wedge c_5] \quad (4) \end{aligned}$$

A population weighted regression analysis is performed with binomial variances $\sigma^2 = \hat{Y}(1 - \hat{Y})/N$, where N is the number of live births plus stillbirths.

To test the significance of the strontium term $Sr(t)$, an F-test is used. The F-value has to be corrected for overdispersion to allow for model uncertainties. A detailed description of the methods is given elsewhere.[10] The F-value is determined by

$$F = (S_0 - S_1) / (df_0 - df_1) / (S_1/df_1) \quad (5)$$

where S_0 and S_1 are the weighted sum of squares obtained from regressions without and with the strontium term, respectively, and df_0 and df_1 are the degrees of freedom. The expression S_1/df_1 in the denominator is the overdispersion factor. The p-value for the strontium effect results from an F-test with $(df_0 - df_1, df_1)$ degrees of freedom.

Results

Fallout data for the years before 1958 were not available for Germany. Atmospheric tests started in 1952, with a period of intensive testing in the years 1952–1954. To account for the sum effect of the fallout years before 1958, the amount of fallout in a given year $k < 1958$ was estimated by regressions with equation 4, and with an additional parameter (c_6) for $A(k)$. Individual regressions with $k = 1953$, 1954, and 1955 yielded values for the weighted sum of squares of 402.3, 321.7, and 426.2, respectively. Because the best fit is obtained for $k = 1954$, the year 1954 was used as a proxy for all fallout years before 1958. The fact that the proxy year was determined from the data requires an additional parameter, which has to be considered in the F-test.

To determine the significance of the strontium term, an F-test was applied. The sum of squares resulting from regressions without (S_0) and with (S_1), the strontium terms were $S_0 = 4144.5$ ($df_0 = 36$) and $S_1 = 321.7$ ($df_1 = 32$). The strontium term was highly significant ($F = 95.1$, $p < .0001$).

The results of the regression analysis, i.e., the estimates of the parameters, the standard deviations (*SD*), the *t*-values, and the corresponding *p*-values are given in Table 1.

The power of dose in the strontium term was significantly greater than 1, and the dose response relationship was supralinear (c_5 = 1.81 ± 0.23). The improvement of the fit compared with a model using a linear dose-response relationship—with c_5 = 1—was highly significant (S_0 = 528.1, [df_0 = 33], S_1 = 321.7 [df_1 = 32]; p = 0.0001). Parameter c_1 in equation 1, the natural limit of perinatal mortality, is estimated at 2.15 ± 0.93 deaths per 1,000 live births plus stillbirths (p = 0.0274).

From the difference between observed perinatal mortality rates and the undisturbed trend, a cumulative number of 104,372 excess deaths was determined.

Figure 1 shows the trend of perinatal mortality data and the result of the regression analysis. The broken line is the undisturbed trend line. The columns are proportional to the strontium concentration in the fallout. Considering the long time span of 39 yr and the approximations used, the model fits the data remarkably well. Figure 2 displays the excess perinatal mortality rates, which are the differences between the observed rates and the undisturbed trend.

Table 1.—Results of the Analysis of Perinatal Mortality Data

Parameter	Estimate	*SD*	*t*	*p*
c_1	2.1513	0.9323	2.308	0.0274
c_2	−3.1476	0.0200	−157.3	<0.0001
c_3	−0.0686	0.0065	−10.55	<0.0001
c_4	9318.9	9448.5	0.986	0.3313
c_5	2.7437	0.2739	10.02	<0.0001
c_6	1.8075	0.2346	7.705	<0.0001

Note: *SD* = 1 standard deviation.

Combined regression analysis. Data for number of stillbirths and early neonatal deaths—the two subgroups of perinatal deaths—were available, so individual regressions to the two data subsets were performed. We hypothesized that if the same model fit both data sets, the plausibility of the model would be affirmed.

The results for the parameters are compared in Table 2. Parameter c_5 (the power of dose in the strontium term) and parameter c_6 (the amount of strontium fallout in 1954) agree within the limits of error. Therefore, a combined regression analysis of the two data subsets could be performed with common parameters for the power of dose and A(1954). The regression model has the form:

$$\begin{aligned} Y(t) = {} & \{c_1+(1-c_1)/[1+1/\exp(c_2+c_3\cdot t)]\} \\ & \cdot SB + \{c_4+(1-c_4)/[1+1/\exp(c_5+c_6\cdot t)]\} \\ & \cdot (1-SB) + [c_7\cdot SB + c_8\cdot(SB-1)] \\ & \cdot \Sigma_{k<t} conc(t,k)\text{^}c_9 \end{aligned} \quad (6)$$

where the dummy variable, *SB*, indicates the two data sets (*SB* = 1 for stillbirths, and *SB* = 0 for early neonatal deaths). Parameter c_{10} = A(1954) is hidden in $\Sigma_{k<t} conc(t, k)$.

The sum of squares obtained from a regression with the full model is S_1 = 497.0 (df_1 = 67), whereas a regression without the strontium terms yields S_0 = 5439.3 (df_0 = 72). The improvement of the fit with the

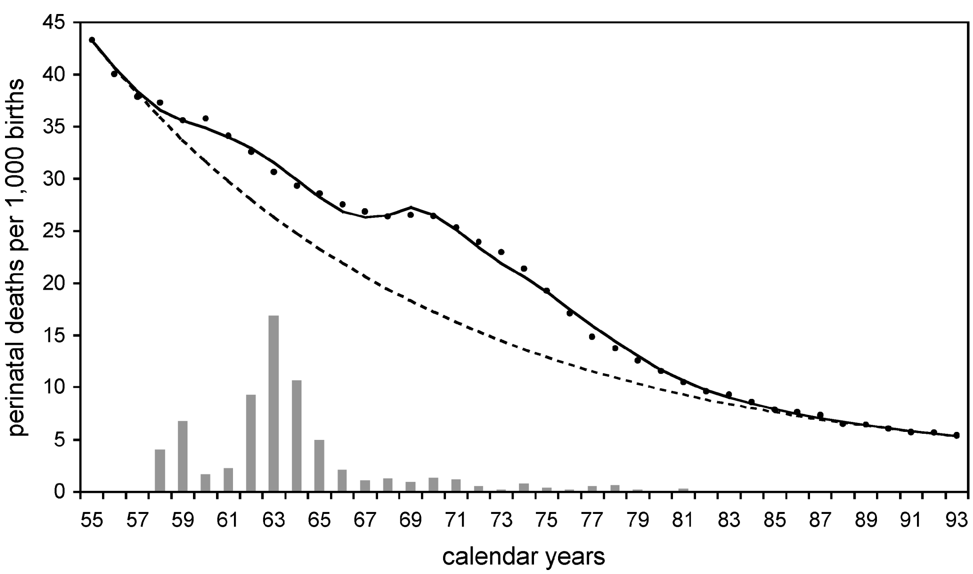

Fig. 1. Perinatal mortality rates (•) in West Germany and trend line resulting from a weighted regression analysis (solid line). The undisturbed trend is shown by the broken line. The columns indicate the strontium concentration in the fallout (in arbitrary units).

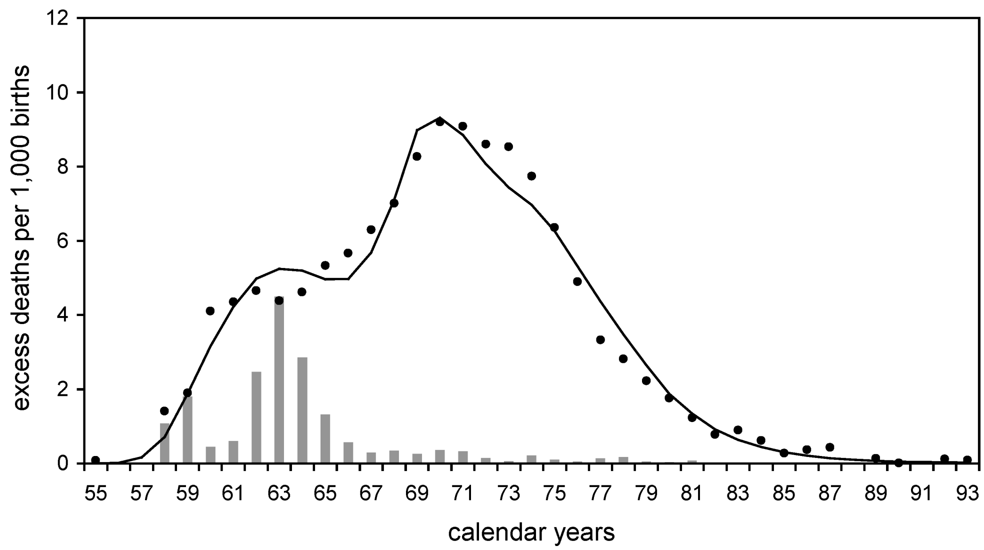

Fig. 2. Excess perinatal mortality rates (•). Excess perinatal mortality rates equal the observed rates minus the undisturbed trend. Regression results are shown by the solid line. The columns indicate the strontium concentration in the fallout (in arbitrary units).

Table 2.—Comparison of Results for Stillbirths and Early Neonatal Deaths

	Stillbirth rate		Early neonatal mortality	
Parameter	Estimate	*SD*	Estimate	*SD*
c_1	1.9360	0.3003	0.3659	0.7611
c_2	−4.0131	0.0138	−3.7159	0.0289
c_3	−0.0729	0.0062	−0.0672	0.0089
c_4	588.70	659.93	9243.8	10596.6
c_5	3.1108	0.5998	2.7442	0.2833
c_6	1.5203	0.2608	1.8601	0.2642

Note: *SD* = 1 standard deviation.

Table 3.—Results of the Combined Regression Analysis

Parameter	Estimate	*SD*	*t*	*p*
c_1	1.7234	0.3508	4.913	<0.0001
c_2	−4.0072	0.0165	−242.3	<0.0001
c_3	−0.0684	0.0054	−12.79	<0.0001
c_4	0.4046	0.5512	0.734	0.4655
c_5	−3.7165	0.0208	−178.3	<0.0001
c_6	−0.0678	0.0066	−10.31	<0.0001
c_7	2435.7	1970.2	1.236	0.2207
c_8	8238.2	6619.0	1.245	0.2174
c_9	1.8349	0.1843	9.955	<0.0001
c_{10}	2.7570	0.2095	13.16	<0.0001

Note: *SD* = 1 standard deviation.

full model is highly significant ($p < 0.0001$, F-test). The results of the combined regression are given in Table 3.

The natural lower limit for stillbirth rates is significantly greater than zero ($c_1 = 1.72 \pm 0.35$ per 1,000 live births plus stillbirths; $p < 0.001$), but the natural limit for early neonatal mortality is not significantly greater than zero ($c_4 = 0.40 \pm 0.55$ per 1,000 live births; $p = 0.466$). The ratio of the amplitudes c_8 and c_7 in the strontium terms is 3.4; therefore, the effect of the strontium term is much greater for early infant deaths than for stillbirths. The dose-response curve is curvilinear with a power of dose of $c_9 = 1.83 \pm 0.18$. The regression results in a cumulative excess number of 24,102 stillbirths and 80,651 early infant deaths over the observation period. The trends of the data and the excess rates are shown in Figure 3 and Figure 4.

Discussion

We found a highly significant correlation between perinatal mortality rates in West Germany and the calculated strontium burden in pregnant women. The model applies to stillbirth as well as early neonatal mortality data. The undisturbed trend of stillbirth data approaches a "natural" lower limit. This is contrary to early neonatal mortality data, for which the lower limit is not significantly greater than zero. The peak deviations from an undisturbed downward trend coincide in the two data sets. The dose-response relationship is nonlinear; the power of dose agrees in both data sets within the limits of error. The strontium effect is 3.4 times greater for early neonatal mortality than for stillbirth. Contrary to former studies, this analysis is not based on an extrapolation method, but instead

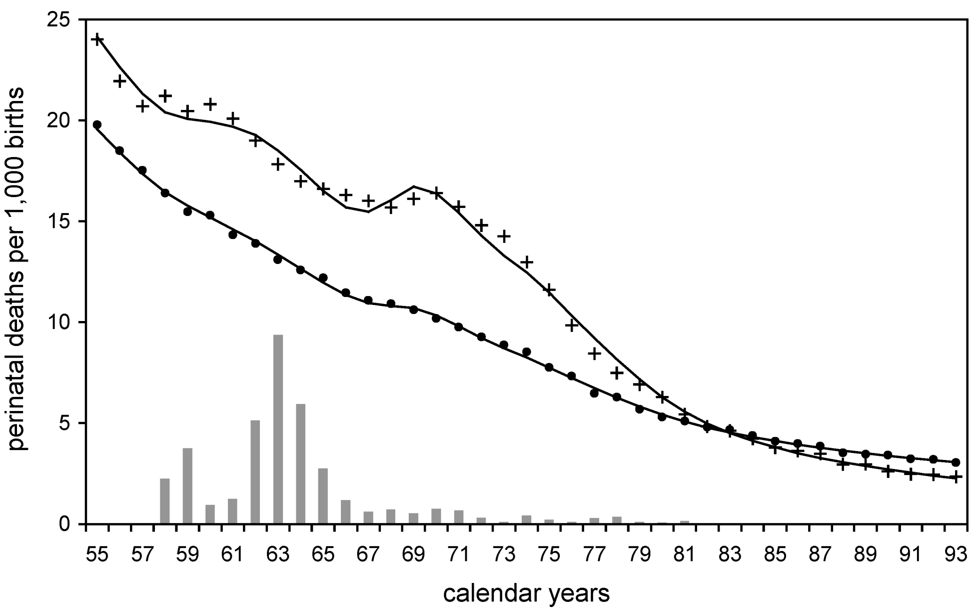

Fig. 3. Stillbirth (•) and early neonatal mortality rates (+) in West Germany and result of a combined regression analysis (solid lines). The columns indicate the strontium concentration in the fallout (in arbitrary units).

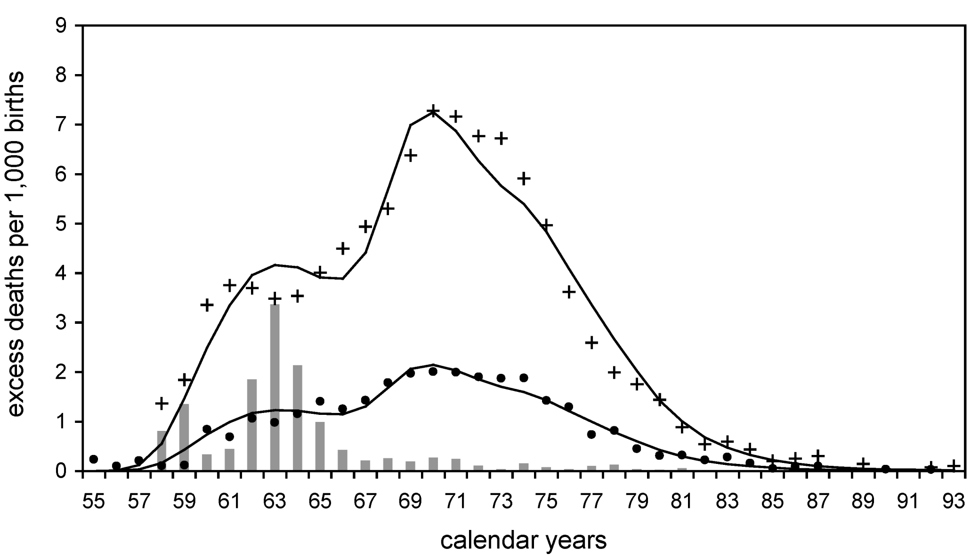

Fig. 4. Excess stillbirth (•) and early neonatal mortality (+) rates (observed mortality rates minus undisturbed trend determined from the regression analysis). The solid lines are the results of a combined regression analysis. The columns indicate the strontium concentration in the fallout (in arbitrary units).

uses all available West German data for the years 1955–1993.[2,7]

It could be argued that a good fit to the data should be expected when a large number of parameters—in this case, six—is used in the model. But if this were true, an even better fit to the data would be expected with a polynomial fit without any model restrictions. The sum of squared residuals was used to compare the goodness of fit for the two models. But a polynomial model, also with six parameters, yields a sum of squares of S = 894.9, which is much greater than the value obtained with the regression model used in this study (S = 321.7).

Under the model's assumptions, about 80,000 excess early neonatal deaths in West Germany can be attributed to strontium from the fallout of atmospheric nuclear weapons tests. More than 50% of all early neonatal deaths occur within the first 24 h of an infant's life. Thus, the number of excess cases in West Germany (population 60 million) is well compatible with an estimated 37,000 excess first-day neonatal deaths in England and Wales (population 50 million) and with 195,000 excess first-day neonatal deaths in the United States (population over 200 million).[7]

Official estimates of the dose to the bone marrow from strontium-90 were only a fraction of 1 mGy in 1963, the year of peak fallout. This dose is considered too low to produce any measurable effect on infant mortality. Therefore, the obvious peaks in the trend of infant mortality and first-day neonatal mortality in the United States, closely related to the atomic weapons tests, would remain unexplained.[2,7]

According to the prevailing wisdom, the fetus is protected against damage from low-level ionizing radiation below a threshold dose of 100 mSv.[11] The findings of this study suggest that the existence of a safe dose for deterministic effects of ionizing radiation must be questioned. However, because the study is based on highly aggregated data, other possible influences that might explain the effect cannot be excluded. Further independent confirmation should be sought by testing the model on other data sets, such as data from United States.

* * * * * * * * * *

Alfred Körblein retired from the Munich Environmental Institute at the end of 2004.

Submitted for publication December 2, 2004; accepted for publication June 16, 2005.

Reprint requests should be sent to Alfred Körblein, Untere Soeldnersgasse 8, D-90403, Nurenberg, Germany.
E-mail: alfred.koerblein@gmx.de

* * * * * * * * * *

References

1. United Nations Scientific Committee on the Effects of Atomic Radiation. UNSCEAR 1993 Report to the General Assembly. New York: United Nations, 1993.
2. Sternglass EJ. Infant mortality and nuclear tests. Bull At Sci 1969; 25:26–8.
3. Gould JM, Sternglass EJ. Nuclear fallout, low birthweight, and immune deficiency. Int J Health Serv 1994; 24(2):311–35.
4. Lindop P, Rotblat J. Strontium-90 and infant mortality. Nature 1969; 224(226):1257–60.
5. Shaw RF, Smith AP. Strontium-90 and infant mortality in Canada. Nature 1970; 228(272):667–9.
6. Fuchs VR. Low-level radiation and infant mortality. Health Phys 1981; 40(6):847–54.
7. Whyte RK. First day neonatal mortality since 1935: re-examination of the Cross hypothesis. BMJ 1992; 304(6823):343–6.
8. Tolstykh EI, Kozheurov VP, Vyushkova OV, et al. Analysis of strontium metabolism in humans on the basis of the Techa river data. Radiat Environ Biophys 1997; 36:25–9.
9. International Commission on Radiological Protection. Age dependent doses to members of the public from intake of radionuclides: Part 2: Ingestion dose coefficients (ICRP Publication 67). Ann ICRP 1993; 23(3–4).
10. Korblein A, Kuchenhoff H. Perinatal mortality in Germany following the Chernobyl accident. Radiat Environ Biophys 1997; 36(1):3–7.
11. International Commission on Radiological Protection. Biological effects after prenatal irradiation (embryo and fetus) (ICRP Publication 90). Ann ICRP 2003; 33(1–2).

Appendix

Perinatal Mortality Data, West Germany

Calendar year	Live births	Stillbirths	0–6 d
1955	820,128	16,558	19,699
1956	855,887	16,129	18,780
1957	892,228	15,911	18,470
1958	904,465	15,082	19,190
1959	951,942	14,951	19,466
1960	968,629	15,049	20,137
1961	1,012,687	14,704	20,342
1962	1,018,552	14,361	19,353
1963	1,054,123	13,991	18,793
1964	1,065,437	13,590	18,090
1965	1,044,328	12,901	17,342
1966	1,050,345	12,174	17,121
1967	1,019,459	11,422	16,317
1968	969,825	10,702	15,205
1969	903,456	9,693	14,552
1970	810,808	8,351	13,301
1971	778,526	7,674	12,239
1972	701,214	6,557	10,377
1973	635,633	5,686	9,060
1974	626,373	5,387	8,128
1975	600,512	4,689	6,967
1976	602,851	4,444	5,936
1977	582,344	3,794	4,916
1978	576,468	3,650	4,314
1979	581,984	3,325	4,026
1980	620,657	3,308	3,904
1981	624,557	3,204	3,401
1982	621,173	2,996	3,000
1983	594,177	2,790	2,748
1984	584,157	2,567	2,474
1985	586,155	2,414	2,217
1986	625,963	2,506	2,268
1987	642,010	2,485	2,235
1988	677,259	2,398	1,998
1989	681,537	2,368	2,023
1990	727,199	2,490	1,904
1991	722,250	2,345	1,791
1992	720,794	2,310	1,769
1993	717,899	2,192	1,690

Decision editor: Kaye H. Kilburn, MD