Chernobyl Fallout and Outcome of Pregnancy in Finland

Anssi Auvinen,[1,3] Mikko Vahteristo,[2] Hannu Arvela,[1] Matti Suomela,[1] Tua Rahola,[1] Matti Hakama,[3] and Tapio Rytömaa[1,*]

[1]STUK–Radiation and Nuclear Safety Authority, Helsinki, Finland; [2]National Public Health Institute, Department of Environmental Epidemiology, Kuopio, Finland; [3]Tampere School of Public Health, University of Tampere, Tampere, Finland

Possible effects of Chernobyl fallout on outcome of pregnancy in Finland were evaluated in a nationwide follow-up study. The outcomes were the rate of live births and stillbirths, pregnancy loss, and induced abortions by municipality. Exposure was assessed based on nationwide surveys of radiation dose rate from the Chernobyl fallout, from both external and internal exposures. Using these measurements, we estimated the monthly dose rate for each of the 455 Finnish municipalities. On average, the dose rate from Chernobyl fallout reached 50 µSv per month in May 1986—a doubling of the natural background radiation. In the most heavily affected area, 4 times the normal background dose rates were recorded. Given the underlying regional differences in live birth, stillbirth, and abortion rates, we used longitudinal analysis comparing changes over time within municipalities. A temporary decline in the live birth rate had already begun before 1986, with no clear relationship to the level of fallout. A statistically significant increase in spontaneous abortions with dose of radiation was observed. No marked changes in induced abortions or stillbirths were observed. The decrease in the live birth rate is probably not a biological effect of radiation, but more likely related to public concerns of the fallout. The effect on spontaneous abortions should be interpreted with caution, because of potential bias or confounding. Further, there is little support in the epidemiologic literature on effects of very low doses of radiation on pregnancy outcome. *Key words*: adverse effects, birth rate, Finland, induced abortion, pregnancy outcome, radiation, spontaneous abortion, stillbirth. *Environ Health Perspect* 109:179–185 (2001). [Online 26 January 2001]

http://ehpnet1.niehs.nih.gov/docs/2001/109p179-185auvinen/abstract.html

Ionizing radiation can cause congenital malformations, retardation of intrauterine growth, and embryonic death (*1*). The type of manifestation depends mainly on the timing of radiation exposure during pregnancy: very early (before the blastocyst phase) loss of pregnancy is the most likely adverse effect because the embryonal cells are still totipotent (i.e., able to differentiate into any type of cell), whereas the period of organogenesis is sensitive to multiple organ teratogenesis and embryonic death. For radiation protection, the limit for radiation exposure to the pregnant woman has been set as 2 mSv during pregnancy (*2*).

Fallout from the Chernobyl accident in 1986 caused radiation doses up to 1 mSv during the first year in the European countries (*3*). The health effects reported so far include an increase in both induced (*4*) and spontaneous abortions (*5,6*). Also, a temporary decline in birth rates has been reported from some countries (*7,8*). The causes of this decline have not been explored empirically. It has been assumed that psychological effects are the cause, because the doses seem too low to account for early pregnancy loss.

Our aim was to assess the effects of Chernobyl fallout on birth rate, induced abortions, and pregnancy loss in Finland. Occurrence of congenital malformations as well as perinatal mortality were outside the scope of this study.

Materials and Methods

We aimed to identify all possible outcomes of pregnancy (induced abortion, loss of pregnancy, and birth) from central registries available in Finland. The data were collected at municipality level. There are 455 municipalities in Finland with populations from 500 to 500,000.

We obtained data on the number of women in fertile ages (15–44 years) by 5-year age group and municipality in 1986 from Statistics Finland (Helsinki, Finland). We obtained data on the rates of live births and stillbirths by month and municipality from Statistics Finland for the years 1977–1992. Stillbirths were defined based on either gestational age ≥ 22 weeks or weight ≥ 500 g from January 1987. (An earlier definition had been based on a gestational age of 28 weeks or more.) The monthly number of live births in the whole country was on average 5,000–5,500 and the mean monthly number of stillbirths was 20–30.

We obtained data on induced abortions by months and municipality from the National Research and Development Centre for Welfare and Health (STAKES; Helsinki, Finland) for the years 1983–1992. The indications for abortion were classified in the official statistics as medical indication for fetal reasons, medical indication for maternal reasons, and social indication (including maternal age at conception < 17 or > 40 years; 4 or more previous children; stressful life conditions; criminal conditions of conception; or mother's or father's illness). For induced abortions, the main end point was induced abortions with medical indication for fetal reasons, but induced abortions with social or psychological indications were also of interest. The total number of induced abortions per month was approximately 1,000 for the whole country. Of these, more than 95% were performed for social or psychological indications and only approximately 1% for fetal indications (approximately 150 per year) (*9*).

Data on spontaneous abortions by months and municipality were obtained from the Hospital Discharge Registry (Helsinki, Finland) for the years 1977–1992 (*10*). Spontaneous abortion was defined as any of the following diagnoses [as coded by the *International Classification of Disease, 9th Revision* (ICD9)]: spontaneous abortion (ICD9 codes 6,340–6,349), ovum abortivum (ICD9 code 6,310), or missed abortion (ICD9 code 6,320). Mola hydatidosa (ICD9 code 6,300) and ectopic pregnancy (ICD9 codes 6,330–6,339) were excluded from the study. The mean monthly number of spontaneous abortions in Finland was approximately 550–650.

The expected numbers of each type of outcome were calculated for each municipality based on the number of women in fertile ages and using the national rate from the pre-Chernobyl period as the reference (1977–1985 for live births and spontaneous abortions, 1983–1985 for induced abortions). We combined the data using the official municipality numbers as identifiers. All the unions of municipalities that had taken place during the study period were dealt with by pooling data for the united municipalities for all periods.

Radiation exposure. The cumulative dose equivalent over 2 years after the accident (April 1986–March 1988) was calculated

Address correspondence to A. Auvinen, STUK–Radiation and Nuclear Safety Authority, Radiobiology Laboratory, PO Box 14, FIN-00881 Helsinki, Finland. Telephone: +358-9-759 88 554. Fax +358-9-759 88 556. E-mail: anssi.auvinen@stuk.fi

*Current address: Department of Environmental Sciences, University of Kuopio, Kuopio, Finland.

Received 16 August 1999; accepted 30 October 2000.

taking into account both external and internal radiation dose. To assess the effects of radiation, we divided the population into fifths (Q1–5) by radiation exposure. Also, we calculated the dose rate for each month for the first 12 months after the accident.

The dose estimates are based on a mobile survey on fallout levels in Finland after the Chernobyl accident (*11*). Continuous measurements were made with a germanium spectrometer while the vehicle was driven; the results thus represent the average fallout level of each section of the route. We measured 19,000 km between May 1986 and August 1987. Calibration was carried out by taking soil samples at calibration sites. The passage of the Chernobyl plume over Finland led to various fallout patterns for different radionuclides. The survey results present fallout patterns of cesium-137, zirconium-95, and ruthenium-106. Both the geographical variations in rain intensity in different periods after the accident and the time variations in radionuclide composition of atmospheric releases affected the fallout patterns. The population doses were caused overwhelmingly by ^{137}Cs and other volatile nuclides strongly correlated to its activity distribution. The effect of delay in measurement was corrected by using a back-calculation technique taking into account both radioactive decay and washout effect.

For each municipality, we calculated the mean dose rate based on spectrometric measurements. We accounted for the shielding effect of buildings by using a shielding factor based on the proportion of blocks of flats in each municipality. We subtracted the dose rate from the fallout of atmospheric atomic bomb testing, known from previous measurements, from our results. We classified all the municipalities on the basis of external dose rate to form population fifths with roughly similar population sizes. A more detailed description of the methods has been published elsewhere (*11,12*).

We assessed internal exposure as delivered effective dose, using whole-body counting measurements performed on a random sample of women of child-bearing age (15–44 years). The subjects (*n* = 117) were identified through stratified random sampling from the Population Registry (Helsinki, Finland), with stratification by province and age. One or two whole-body counting measurements were performed on each between May 1986 and April 1988. The internal doses were calculated by using individual body contents of ^{134}Cs and ^{137}Cs expressed as becquerels per body weight in kilograms. The activity time integrals (becquerels per year per kilogram) were calculated separately for each of the nuclides, taking into account the variation in body contents over time. The mean value of the whole-body counting measurements was assigned to each population fifth on the basis of whole-body counting measurements of subjects with municipality residence in each group. The limited number of whole-body counting measurements meant that municipality-specific values could not be derived; therefore, the mean value for the population fifth was assigned to each municipality within it. More detailed description of the procedures has been published previously (*12–15*).

Statistical methods. We calculated standardized rates of each outcome (live birth, spontaneous abortion, and induced abortion) by comparing their observed and expected frequencies. The population at risk was defined as women in fertile ages (15–44 years). We calculated the expected numbers of each event for each municipality using the number of women in fertile ages (15–44 by 5-year age groups) and the reference rates, which were calculated from the national rates. We calculated the reference rate for each event by linear interpolation between the pre-Chernobyl period (up to April 1986) and the post-Chernobyl period (from May 1988 onward). The expected numbers were month-specific, e.g., calculation of expected numbers for January 1987 was based on rates from January of both earlier and later years. Thus, both underlying trend and seasonal variation in fertility could be taken into account. Lagging was performed by assigning the dose rate from the time 9 months earlier to the date of birth (e.g., dose rate in May 1986 to birth rate in February 1987). Analyses were conducted both with and without lagging for stillbirths, and no lagging was used in the analyses of induced or spontaneous abortions.

In the analyses, we used the monthly mean dose rate (microsieverts per month) in each municipality as the explanatory variable, and the ratio of expected and observed number of outcome events as the dependent variable. We performed a longitudinal analysis of the monthly rate of outcomes and monthly dose rate by municipality dose-rate using mixed-effects models (SAS PROC MIXED; SAS Institute, Cary, NC, USA) that account for the fact that monthly rates in the same municipality are not independent. In the model, the standardized incidence ratio (SIR) of pregnancy outcome (y) was described in terms of fixed effects of dose rate (x_1) and municipality (x_2) with an error term ε, i.e.,

$$y = \beta_1 x_1 + \beta_2 x_2 + \varepsilon, \qquad [1]$$

where both prevalence and dose rate were measured repeatedly for the same set of municipalities. No other covariates were used. An identity link was used, so the regression intercept β gives the absolute change in SIR of outcome per unit change in dose rate (microsieverts per month). Statistical significance was assessed using a Wald test.

No informed consent was needed, because only aggregate data were used.

Results

Initially, the mean dose rate for the whole country reached a value of 0.07 µSv/hr or 50 µSv/month in May 1986 and then declined rapidly (Figure 1). For the municipalities with the highest exposure, the external effective dose rate was initially above 200 µSv/month (0.27 µSv/hr), but did not exceed 50 µSv/month (0.07 µSv/hr) after December 1986 in any municipality. The mean dose equivalent among women 15– 44 years of age in May 1986 is shown in Table 1. The cumulative dose during the first 2 years was 0.4 mSv for the whole population and 1.0 mSv for the population fifth with the highest exposure.

There was some underlying variation in pregnancy outcome by geographical region before the accident (Table 2). The area with the lowest level of fallout had higher rates of births, induced and spontaneous abortions, and stillbirths.

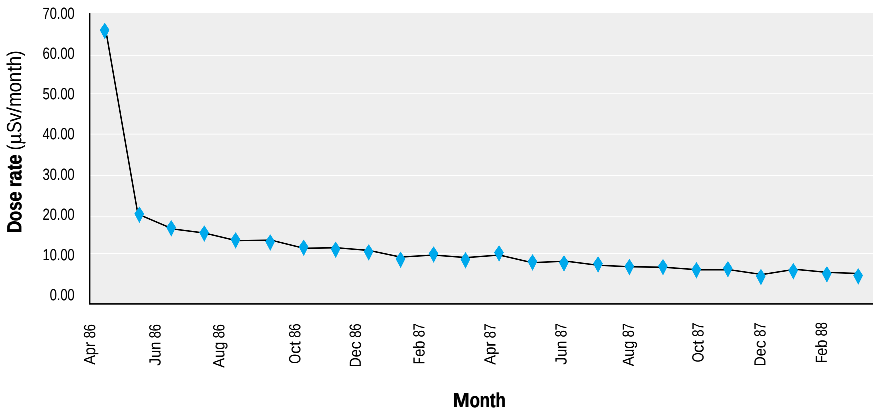

Figure 1. External dose rate in Finland after the Chernobyl accident, April 1986–March 1988.

A temporary decline in the number of live births had already begun before the accident (Figure 2). Nine months after the accident, in February 1987, the standardized birth rate was at its lowest, 10% below the reference level. However, this was not statistically significant compared to the early months after the accident, when it was approximately 5% below the reference level.

A slight decrease in the number of stillbirths was observed following the accident, compared to the pre-1986 rates (Figure 3). This pattern was comparable among all exposure fifths. There was a slight decrease in the number of spontaneous abortions in 1987 in the whole country, with no evidence for an increase in the most heavily affected areas (Figure 4).

In the overall number of induced abortions with fetal indications, an increasing trend continued throughout the study period without major changes around 1986 (Figure 5). We saw no clear decrease in the population fifth with the highest dose rate compared to other fifths. The numbers of induced abortions with social or psychological indications were quite stable with no apparent increase following the Chernobyl accident (Figure 6). We observed a similar pattern for the most heavily affected areas, as for the rest of the country.

The longitudinal analysis using the monthly municipality-specific rate for each outcome in May 1986–April 1987 and dose rate from Chernobyl fallout showed no association between live birth rate and higher dose rate, using lagging of dose by 9 months (Figure 7, Table 3). No association with stillbirths was observed, whether using lagged or nonlagged dose rate (Figure 8, Table 3). The rate of spontaneous abortions increased slightly with dose rate (Figure 9, Table 3). For induced abortions with psychosocial indications, no clear association with the dose rate emerged (Figure 10, Table 3). No increase in abortions with fetal indications was associated with dose rate (Figure 11, Table 3).

Discussion

The radiation doses from the Chernobyl fallout in Finland were relatively low compared to, for example, doses from radiologic examinations, even though Finland was one of the most heavily affected countries outside the former USSR. Nevertheless, there was a doubling of the normal dose rate from natural background radiation in the early phases for the whole country, and in the most heavily affected areas the dose rate more than tripled. We analyzed the relationship between temporal changes in pregnancy outcomes and dose rate from the accident within each Finnish municipality following the Chernobyl accident. In the whole country, the live birth rate had already been decreasing before the accident, and postaccidents rates were not associated with the fallout. We observed no clear increase in induced abortions with social or psychological indications, nor in those with fetal indications. We did see some indication of an increase in spontaneous abortions in the areas with the highest level of fallout.

However, our findings must be interpreted with caution because there is little support for effects of low doses and dose rates of radiation on pregnancy outcome in the literature. No increase in spontaneous abortions has been reported (e.g., in other countries exposed to Chernobyl fallout or in areas with high background radiation), even though stratification by exposure level had not been used in the studies published earlier.

Knowledge concerning the effects of ionizing radiation on outcome of pregnancy is largely based on studies of atomic bomb survivors and their offspring. Radiation exposure *in utero* has been shown to cause abnormalities such as mental retardation and a range of morphologic abnormalities (*1*). The most sensitive period for these is from the 8th until the 15th week of gestation, and the risk increases in a linear manner with radiation dose. However, little is known about the risk of miscarriage following exposure to low-dose radiation. In principle, there is a clone of equipotent cells in an

Table 1. The mean dose equivalent in May 1986 (µSv) from the Chernobyl accident in Finland by population fifth ranked by exposure.

Population fifth[a]	External exposure	Internal exposure	Total
I (lowest)	6.4	0.2	6.6
II	12.8	0.2	13.0
III	30.8	0.2	31.0
IV	69.6	0.4	70.0
V (highest)	137.4	0.5	137.9
Whole country	51.4	0.3	51.7

[a]The number of subjects (women 15–44 years of age) for whole-body counting measurements by population fifth (from I to V) were 28, 22, 23, 20, and 24, respectively.

Table 2. The relative risk of birth, spontaneous abortion, induced abortion due to fetal indications, and stillbirths (95% CI) by population fifth before the Chernobyl accident.

Population fifth	Birth rate[a]	Spontaneous abortions[a]	Induced abortions (fetal indication)[b]	Stillbirths[a]
I (lowest)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
II	0.80 (0.78–0.82)	0.87 (0.81–0.92)	0.69 (0.50–0.96)	0.70 (0.60–0.80)
III	0.88 (0.86–0.91)	0.93 (0.87–0.99)	0.66 (0.47–0.91)	0.81 (0.70–0.94)
IV	0.91 (0.89–0.93)	0.97 (0.91–1.04)	0.66 (0.48–0.93)	0.83 (0.72–0.96)
V (highest)	0.89 (0.97–0.92)	0.93 (0.87–1.00)	0.68 (0.48–0.95)	0.74 (0.64–0.86)

[a]1977–1985. [b]1983–1985.

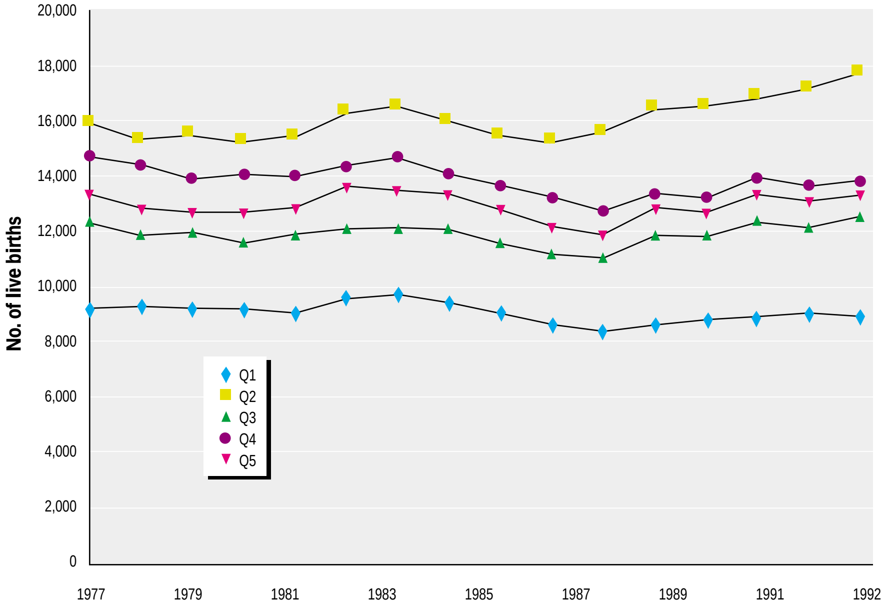

Figure 2. Number of live births by exposure fifth in Finland 1977–1992. Q1: lowest, Q5: highest.

embryo, and compensatory mechanisms such as accelerated division of surviving cells ensures that a single cell death is unlikely to cause any detriment to the fetus (*1*). However, in a small organism such as the embryo, the number of cell deaths required for early miscarriage is probably smaller than for other nonstochastic effects of radiation.

Although it is somewhat controversial, an association between occupational exposure to radiation and *antepartum* fetal death has been suggested (*16,17*), as well as between diagnostic abdominal irradiation and miscarriage (*18*).

Methodological considerations. In our study, we avoided the selection bias and information bias inherent to interview studies of pregnancy outcome and environmental exposure (*19,20*) by using actual measurements of exposure and by obtaining data on end points from registry-based information systems.

Both exposure and outcome were measured only at aggregate level. We assessed exposure based on nationwide surveys of external and internal radiation exposure. However, because the exposure can be regarded as ecological in nature—i.e., homogeneous within a given geographical area, such as a municipality, and modified only to some extent on personal characteristics such as lifestyle or socioeconomic status—the potential for ecological fallacy is small. In an ecological study, misclassification—measurement error due to incomplete assessment—may lead to a bias away from null, causing a false positive finding.

Finland was one of the most heavily contaminated countries outside the former USSR and thus provides a favorable setting for studies of the Chernobyl fallout's effects on health. We were able to use the municipality-specific monthly dose rate as the exposure indicator. There is good biological basis for this approach because the major abnormality in most miscarriages is chromosomal nondisjunction. Radiation can cause nondisjunction; to do so, a hit in the embryonal DNA is required during a short sensitive period in the early phases of development. Thus, the probability that a hit in the embryonal DNA will cause a nondisjunction depends on dose rate at that time; cumulative dose over a longer period is not relevant. For other biological effects of radiation on pregnancy, the dose rate (from both external and internal exposure) is probably as good an exposure indicator as is cumulative dose.

In our study, the validity of exposure assessment was enhanced by taking into account washout effect and radioactive decay. Furthermore, the contribution of fallout from atmospheric atomic bomb testing, known from previous surveys, was subtracted from the measurements. A municipality-specific shielding factor was used, based on the proportion of blocks of flats of all residencies (*12*).

Data on outcomes were also obtained at municipality level, so maternal migration during the pregnancy could not be considered. However, the overall migration rate between municipalities among women at fertile ages in 1986 was relatively small, at 6.2% (*21*). Migration between provinces accounted for only one-fourth of all migration (*21*). Because the differences in exposure between nearby municipalities were small, the possible effect of misclassification is bound to be small.

Expected numbers of each outcome were calculated based on rates in the corresponding month, thus taking into account the strong seasonal variation in fertility (*22,23*). This was especially important because the radiation exposure due to the accident was confined to a short period and then rapidly diminished, inducing potential confounding by season. Also, the underlying trend was taken into account by calculating the expected numbers of each outcome by interpolation between the pre-Chernobyl and the post-Chernobyl periods.

To control for geographical differences in pregnancy outcomes before the accident, we used longitudinal analysis, which accounts for repeated observations within municipality. We were able to classify induced abortions by

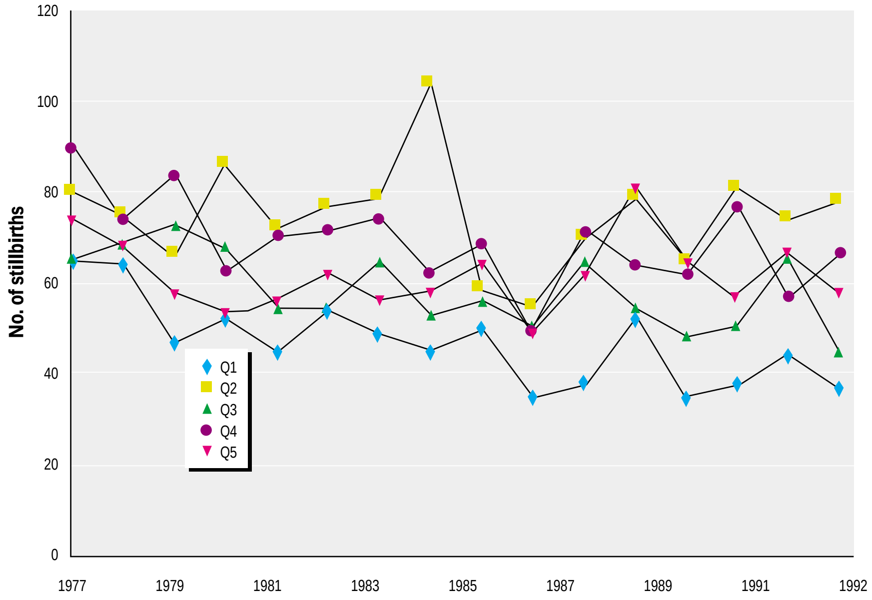

Figure 3. Number of stillbirths by exposure fifth in Finland 1977–1992. Q1: lowest, Q5: highest.

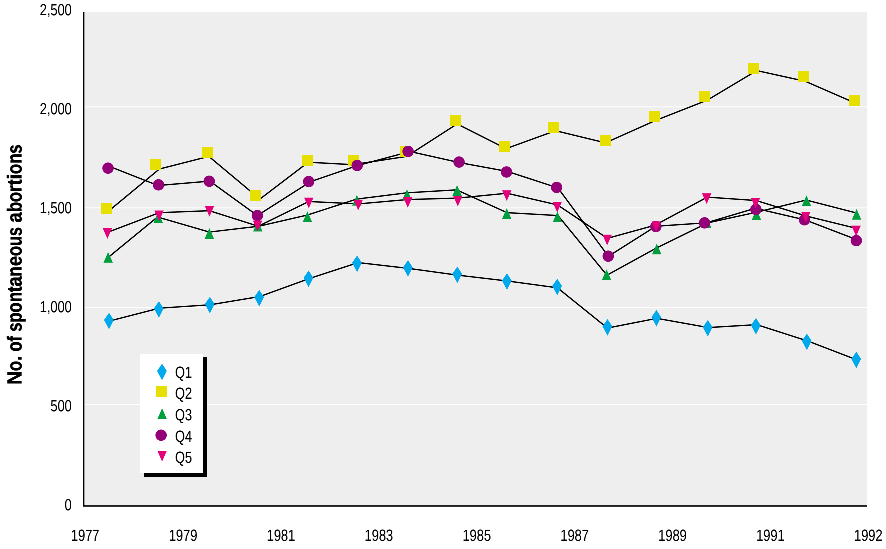

Figure 4. Number of spontaneous abortions by exposure fifth in Finland 1977–1992. Q1: lowest, Q5: highest.

indication and thus had a more specific indicator of outcome than in the previous studies. Induced abortions with fetal indication represent biological effects of radiation, whereas those with social or psychological indication reflect fear and anxiety that can be caused by radiation exposure and may be unrelated to the radiation dose (*24,25*).

The information on the Hospital Discharge Registry has been validated by comparison with hospital records (*26*). There was a 98% concordance in the obstetric diagnoses at the three-digit level in ICD codes.

Birth rate. There was a minor decrease in birth rate following the accident reaching 10% 9 months after the accident. In the longitudinal analysis, we observed no association between dose rate and live birth rate. However, there remains a possibility of early abortion in "subclinical" pregnancy—before the woman is even aware of it—but it is not possible to study empirically without measuring human chorionic gonadotropin (hCG).

In the heavily exposed areas surrounding Chernobyl, there is a much higher probability of radiation-induced effects; other biological effects (e.g., due to nutritional factors) as well as social and psychological distress (e.g., due to evacuations) could also be more prominent (*27,28*).

No clear decrease in birth rate was reported for all of Belarus nor for Ukraine following the accident (*29*). However, a decline by approximately 15–30% in 1987 was observed in the most heavily affected Gomel region in Belarus and for Polesskoe and Narodichi in Ukraine (*7,29*). Either a decrease in the number of planned pregnancies or an increased number of induced abortions could account for this.

A reduction in birth rate following the Chernobyl accident also has been reported in Norway, Sweden, Italy, and Switzerland (*5,8,30,31*). These observations have been attributed primarily to a decreased conception rate. In Greece, the number of live births decreased by 10% in January–March 1987 compared with the years 1981–1986 (*4*); the authors attributed the reduction to induced abortions, but considered no other explanations.

A previous report from Finland (*32*) suggested a smaller decrease in birth rate (0.5%) for January–March 1987. The difference is due mainly to the fact that they did not report monthly rates. Also, the expected numbers were calculated differently.

Stillbirths. In the whole country, stillbirths decreased in proportion to live births, but we observed a nonsignificant increase in December 1986–January 1987. There was some indication of increasing trend of stillbirths with a high dose rate in the longitudinal analysis. However, a change in the definition of stillbirths introduced in 1987 complicated evaluation of temporal trends; the adoption of a broader definition could have introduced an artefactual increase in 1987.

Among previous studies, an increase in perinatal mortality (stillbirths and deaths within 7 days of birth) was reported in Germany in 1987 (*33*). However, a more detailed analysis did not find differences according to fallout level in Bavaria, the most heavily contaminated part of the former Federal Republic of Germany (*34*).

Spontaneous abortions. In our study, we observed no statistically significant increase in spontaneous abortions in the whole country. However, there was a nonsignificant increase

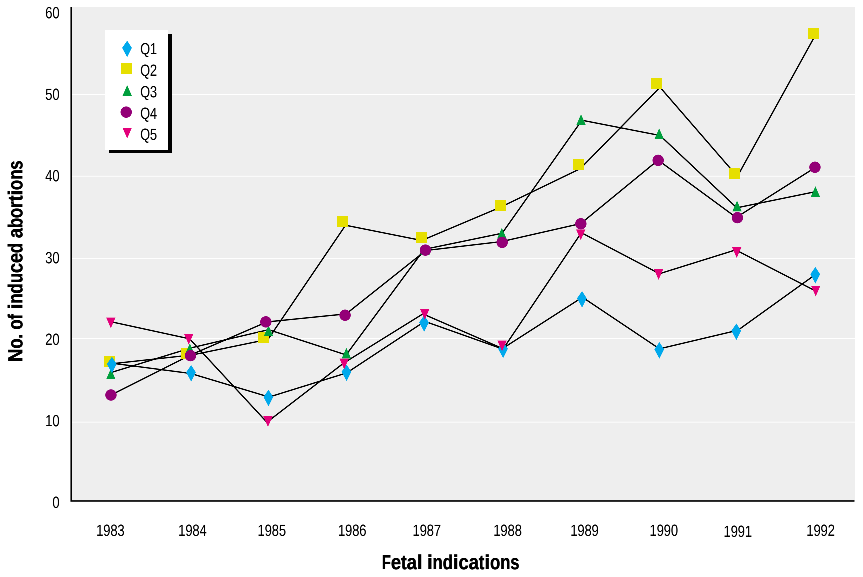

Figure 5. Number of induced abortions due to fetal indications by exposure fifth in Finland 1983–1992. Q1: lowest, Q5: highest.

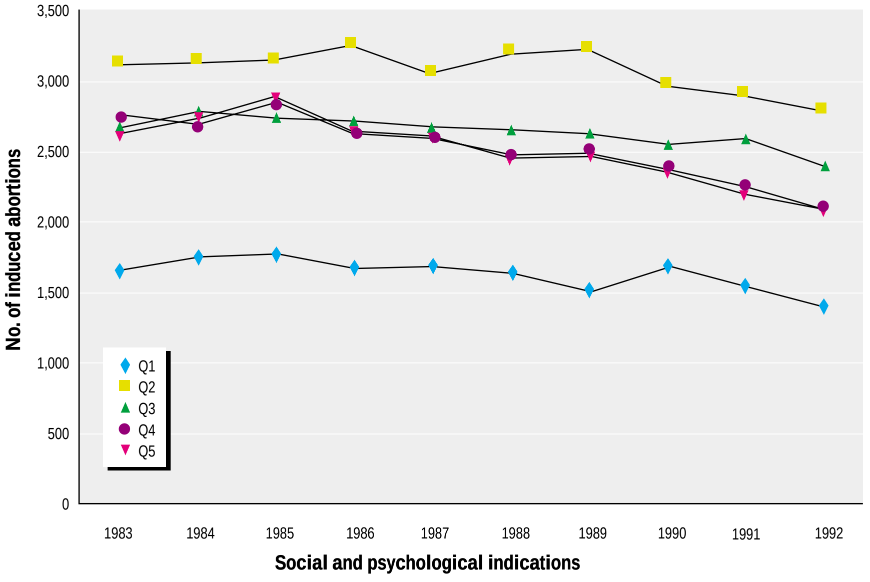

Figure 6. Number of induced abortions due to social and psychological indications by exposure fifth in Finland 1983–1992. Q1: lowest, Q5: highest.

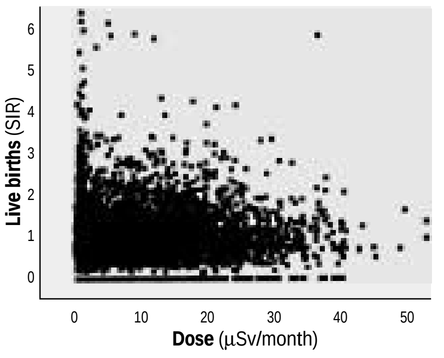

Figure 7. Dose rate and SIR of live births in Finland, May 1986–April 1987.

in July–December 1986. In the longitudinal analysis, a small yet statistically significant increase in spontaneous abortions with dose rate was observed. The estimated magnitude of increase was 1% per microsievert per hour [95% confidence interval (CI), 0.7–1.2]. Given the mean dose rate of 18 µSv/month for the whole in 1986, it would correspond to an 18% excess, i.e., approximately 1,300 excess losses of pregnancy against a background of 7,200. However, no such excess was observed in 1986, but the number of spontaneous abortions was comparable to previous years. Therefore, this could also be due to a simultaneous decreasing trend in spontaneous abortions during 1986–1988 that parallels the decline in dose rate. Such decrease was indeed observed with unusually low rates in 1987 and 1988, rather than an increase in 1986. Therefore, even if the observation is compatible with an effect of the Chernobyl fallout, due to either biological or psychosocial mechanisms, alternative explanations such as bias and confounding must also be considered when interpreting this finding.

Approximately two-thirds of spontaneous abortions are clinically unrecognized (*35*). Thus, they cannot be assessed except by using determination of urinary concentration of hCG. This is not feasible in a large population-based study.

Pregnancy loss is the major effect of radiation exposure occurring in the preimplantation stage of pregnancy. Later, during the fetal period, sensitivity to lethal effects is reduced. It has been suggested that there is a threshold of approximately 0.25 Gy below which no effects are expected (*1*). However, embryonic death has been observed at lower doses in experimental studies (*36*). Therefore, alternatives to a simple threshold model have been suggested to assess the effects of radiation *in utero* (*37,38*). Also, a psychosocial background for the increased rate of spontaneous abortions—fear and anxiety caused by the fallout—is conceivable (*24,25*).

No information on the gestational stage of pregnancy loss was available, so we were not able to analyze the risk of miscarriage by duration of pregnancy at the time of the accident. However, the period with the nonsignificant increase in spontaneous abortions would correspond to 3–6 months of gestational age given conception at the time of the accident.

No changes in occurrence of miscarriages were reported from Ukraine and Belarus for the areas with the highest level of radioactive contamination, with the possible exception of the Narodichi region (*29,39*).

Ulstein et al. (*6*), in a study of Norway, assessed the occurrence of spontaneous abortions in one county in the most heavily exposed area. Higher incidence of spontaneous abortions was found for the 3 years after the Chernobyl accident compared with the 3 years before it. When stratified by month of conception, the increase was observed most clearly for August–November 1986. When the analysis was performed by time of miscarriage, an increasing trend following the accident was observed. The increase over time in spontaneous abortions in Norway was confirmed in a nationwide study, but no association with the fallout was observed (*30*).

In Sweden, there was no clear increase in miscarriages in relation to the radiation exposure among pregnancies at 1–17 weeks at the time of the accident, nor among pregnancies with conception following the accident (*8*). The reference rate was based on pregnancies of at least 17 weeks at the time of the accident. Thus, there is a possibility of bias because early abortions were already excluded from the reference rate.

No increase in spontaneous abortions has been reported in the high background area in China, where the radiation dose rate is similar to that encountered in Finland after the accident (*40*).

Induced abortions. We observed no overall increase in induced abortions in Finland following the Chernobyl accident. Stratification by exposure category did not reveal any clear differences among the areas. In the longitudinal analysis, we found no clear association between dose rate and induced abortions for either fetal or psychosocial indications. Finland has fairly liberal laws concerning abortion, with abortion on social indication relatively easily available until 12 weeks of pregnancy, and illegal abortions are rare. Our finding indicates that there was no major panic among pregnant mothers, because such induced abortions are readily available if the indications are fulfilled (e.g., number of children, maternal age).

Table 3. Longitudinal analysis of dose rate (µSv/hr) and change in standardized incidence ratio of pregnancy outcomes (%).

Outcome	Effect per µSv/hr, % (95% CI)	Significance
Live birth	0.1 (–0.3, +0.5)	0.76
Spontaneous abortion	1.0 (0.7, 1.2)	0.0001
Stillbirth	0.02 (0.00, 0.04)	0.11
All induced abortions	–0.03 (–0.3, +0.3)	0.86
Induced abortions with fetal indications	–0.02 (–0.04, 0.00)	0.11
Induced abortions with psychosocial indications	–0.02 (–0.2, +0.1)	0.89

CI, confidence interval.

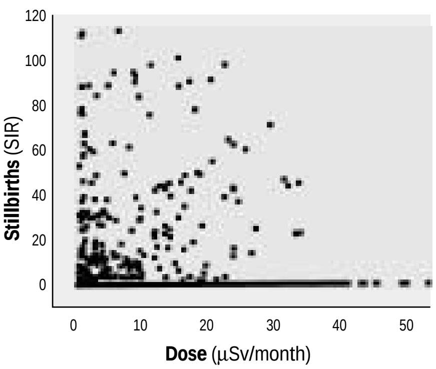

Figure 8. Dose rate and SIR of stillbirths in Finland, May 1986–April 1987.

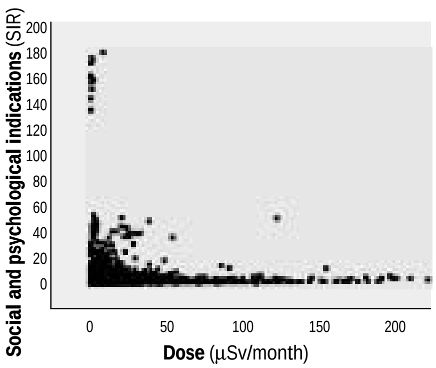

Figure 10. Dose rate and SIR of induced abortions with social and psychological indications in Finland, May 1986–April 1987

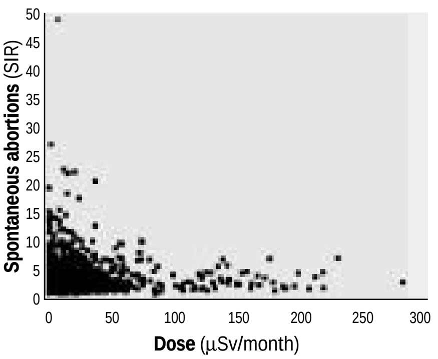

Figure 9. Dose rate and SIR of spontaneous abortions in Finland, May 1986–April 1987.

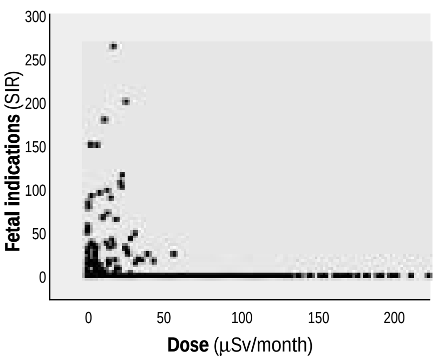

Figure 11. Dose rate and SIR of induced abortions with fetal indications in Finland, May 1986–April 1987.

The effects of the Chernobyl fallout on induced abortions have not previously been reported by indication. In such cases, the induced abortions with social indications dominate in most countries, whereas abortions with fetal indication are a minority, so an effect on the fetus could easily be missed.

An increased rate of induced abortions was reported in Greece, based on decrease in live births following the accident (*4*).

In a Swedish study, an increase in all induced abortions was reported among mothers below 30 years of age in 1986 and 1987 compared to 1985 (*8*). This was observed in the whole country and not associated with the level of fallout. One should, however, note that a statistically significant increase was already detected for the period from January to April (i.e., before the accident), and the rates of induced abortions did not increase above that level before fall 1987. The highest rates were reported for the end of 1987. An earlier report had concluded that the changes in induced abortions were not confined to the time following the accident, but had begun earlier and continued through later years (*41*).

In Italy, a minor increase (3%) was reported in Lombardy, northern Italy, for July 1986, but not for May, June, or August (*31*). No such increase was observed in the central or southern part of the country (Lazio and Campania). For the whole country, some increases in induced abortions were observed mainly in June, July, and September 1986 compared to previous years (*42*). An earlier report suggested a slight increase in induced abortions, but concentrated in June (*43*).

A clear increase by more than 50% in the number of induced abortions was observed in the canton of Ticino in Switzerland in June 1986, but not for other months (*5*).

A study conducted in Denmark reported an increase in induced abortions following the Chernobyl accident (*44*). However, the overall number of abortions in 1986 was not clearly above that for 1985. Also, the highest rates were reported for December and April 1986.

No changes in the rate of induced abortions have been reported for Norway, Hungary, or Austria (*6,30,45,46*).

Previously, Harjulehto et al. (*47*) reported no changes in overall number of legal abortions in Finland. They only reported national rates, not those stratified by region. Furthermore, indication of induced abortion was not available for their study.

In summary, the most notable change in pregnancy outcome following the Chernobyl fallout in Finland was a transient decrease in birth rate that was not related to level of fallout. Also, our data suggest a slight increase in spontaneous abortions in the areas with the highest level of Chernobyl fallout. However, the effect was small and should be interpreted with caution, because earlier epidemiologic studies do not support a biologic effect at low-dose levels, and potential sources of error could account for the finding.

References and Notes

1. UNSCEAR 1993. United Nations Scientific Committee on the Effects of Atomic Radiation. The 1993 Report. New York:United Nations, 1993.
2. ICRP International Commission Radiological Protection. Recommendations of the ICRP. ICRP Publication 60. New York:ICRP, 1990.
3. UNSCEAR 1988. United Nations Scientific Committee on the Effects of Atomic Radiation. The 1988 Report. New York:United Nations, 1988.
4. Trichopoulos D, Zavitsanos X, Koutis C, Drogari P, Proukakis C, Petridou E. The victims of Chernobyl in Greece: induced abortions after the accident. Br Med J 295:1100 (1987).
5. Perucchi M, Domenighetti G. The Chernobyl accident and induced abortions: only one-way information. Scand J Work Environ Health 16:443–444 (1990).
6. Ulstein M, Jensen, TS, Irgens LM, Lie RT, Sivertsen E. Outcome of pregnancy in one Norwegian county 3 years prior to and 3 years subsequent to the Chernobyl accident. Acta Obstet Gynecol Scand 69:277–280 (1990).
7. Kulakov VI, Sokur TN, Volobuev AI, Tzibulskaya IS, Malisheva VA, Zikin BI, Ezova LC, Belyaeva LA, Bonartzev PD, Speranskaya NV, et al. Female reproductive function in areas affected by radiation after the Chernobyl power station accident. Environ Health Perspect 101(suppl 2):117–123 (1993).
8. Ericson A, Källén B. Pregnancy outcome in Sweden after the Chernobyl accident. Environ Res 67:149–159 (1994).
9. Abortions 1993. Helsinki:National Research and Development Centre for Welfare and Health, 1995.
10. Social Welfare and Health Care Statistics and Registers in NAWH. Helsinki:National Research and Development Centre for Welfare and Health, 1994.
11. Arvela H, Markkanen M, Lemmelä H. Mobile survey of environmental gamma-radiation and fall-out levels in Finland after the Chernobyl accident. Radiat Prot Dosim 32:177–183 (1990).
12 Auvinen A, Hakama M, Arvela H, Hakulinen T, Rahola T, Suomela M, Söderman B, Rytömaa T. Fallout from Chernobyl and incidence of childhood leukaemia in Finland, 1976-1992. Br Med J 309:151–154 (1994).
13. Rahola T, Suomela M, Illukka T, Puhakainen M, Pusa M. Radioactivity of people in Finland in 1986. Publication STUK-A64. Helsinki:Finnish Centre for Radiation and Nuclear Safety, 1987.
14. Rahola T, Suomela M, Illukka E, Pusa M. Radioactivity of people in Finland in 1987. Report STUK-A81. Helsinki:Finnish Centre for Radiation and Nuclear Safety, 1990.
15. Rahola T, Suomela M, Illukka E, Pusa S. Radioactivity of people in Finland in 1988. Report STUK-A91. Helsinki:Finnish Centre for Radiation and Nuclear Safety, 1991.
16. Savitz DA, Whelan EA, Kleckner RC. Self-reported exposures to pesticides and radiation related pregnancy outcome—results from National Natality and Fetal Mortality Surveys. Public Health Rep 104:473–477 (1989).
17. Zhang J, Cai W-W, Lee DJ. Occupational hazards and pregnancy outcomes. Am J Ind Med 21:397–408 (1992).
18. Ford JH, MacCormac L, Hiller J. PALS (pregnancy and lifestyle study): association between occupational and environmental exposure to chemicals and reproductive outcome. Mutat Res 313:153–164 (1994).
19. Neutra RR, Swan SH, Hertz-Picciotto I, Windham GC, Wrensch M, Shaw GM, Fenster L, Deane M. Potential sources of bias and confounding in environmental epidemiologic studies of pregnancy outcomes. Epidemiology 3:134–142 (1992).
20. Cordero JF. The epidemiology of disasters and adverse reproductive outcomes: lessons learned. Environ Health Perspect 101(suppl 2):131–136 (1993).
21. Population 1986. Helsinki:Statistics Finland, 1988;80.
22. Rojansky N, Brzezinski A, Schenker JG. Seasonality in human reproduction: an update. Hum Reprod 7:735–745 (1992).
23. Lam DA, Miron JA. Global patterns of seasonal variation in human fertility. Ann NY Acad Sci 709:9–28 (1994).
24. Viinamäki H, Kumpusalo E, Myllykangas M, Salomaa S, Kumpusalo L, Kolmakov S, Ilchenko I, Zhukowsky G, Nissinen A. The Chernobyl accident and mental wellbeing—a population study. Acta Psychiatr Scand 91:396–401 (1995).
25. Havenaar J, Rumyantzeva G, Kasyanenko A, Kaasjager K, Westermann A, van den Brink W, van den Bout J, Savelkoul J. Health effects of the Chernobyl disaster: illness or illness behavior? A comparative general health survey in two former Soviet regions. Environ Health Perspect 105(suppl 6):1533–1537 (1997).
26. Keskimäki I, Aro S. Accuracy of data on diagnoses, procedures and accidents in the Finnish Hospital Discharge Registry. Int J Health Sci 2:15–21 (1991).
27. Vyner HM. The psychological dimensions of health care for patients exposed to radiation and other invisible environmental contaminants. Soc Sci Med 27:1097–1103 (1988).
28. Ginzburg HM. The psychological consequences of the Chernobyl accident—findings from the International Atomic Energy Agency study. Public Health Rep 108:184–192 (1993).
29. The International Chernobyl Project. Assessment of Radiological Consequences and Evaluation of Protective Measures. Report by an International Advisory Committee. IAEA Technical Report. Vienna:International Atomic Energy Agency, 1991.
30. Irgens LM, Lie RT, Ulstein M, Jensen TS, Skjaerven R, Sivertsen F, Reitan JB, Strand T, Skjeldestad FE. Pregnancy outcome in Norway after Chernobyl. Biomed Pharmacother 45:233–241 (1991).
31. Bertollini R, di Lallo D, Mastroiacovo P, Perucci CA. Reduction of births in Italy after the Chernobyl accident. Scand J Work Environ Health 16:96–101 (1990).
32. Harjulehto T, Aro T, Rita H, Rytömaa T, Saxén L. The accident at Chernobyl and outcome of pregnancy in Finland. Br Med J 298:995–997 (1989).
33. Körblein A, Küchenhoff H. Perinatal mortality in Germany following the Chernobyl accident. Radiat Environ Biophys 36:3–7 (1997).
34. Grosche B, Irl C, Schoetzau A, van Santen E. Perinatal mortality in Bavaria, Germany after the Chernobyl reactor accident. Radiat Environ Biophys 36:129–136 (1997).
35. Wilcox AJ, Weinberg CR, O'Connor JF, Baird DD, Schlatterer JP, Canfield RE, Armstrong EG, Nisula BC. Incidence of early loss of pregnancy. N Engl J Med 319:189–194 (1988).
36. Angleton GM, Benjamin SA, Lee AC. Health effects of low-level irradiation during development: experimental design and prenatal and early neonatal mortality in beagles exposed to ^{60}Co γ rays. Radiat Res 115:70–83 (1988).
37. Mays CW. Stochastic and non-stochastic concepts: is revision needed? Health Phys 55:437–441 (1988).
38. Pampfer S, Streffer C. Prenatal death and malformations after irradiation of mouse zygotes with neutrons or X-rays. Teratology 37:599–607 (1988).
39. Buzhievskaya TI, Tchaikovskaya TL, Demidova GG, Koblyanskaya GN. Selective monitoring for a Chernobyl effect on pregnancy outcome in Kiev, 1969–1989. Hum Biol 67:657–672 (1995).
40. High Background Radiation Research Group. Health survey in high background radiation areas in China. Science 209:877–880 (1980).
41. Odlind V, Ericson A. Incidence of legal abortion in Sweden after the Chernobyl accident. Biomed Pharmacother 45:225–228 (1991).
42. Spinelli A, Osborn JF. The effects of the Chernobyl explosion on induced abortions in Italy. Biomed Pharmacother 45:243–247 (1991).
43. Parazzini F, Repetto F, Formigaro M, Fasoli M, La Vecchia C. Induced abortions after the Chernobyl accident. Br Med J 296:136 (1988).
44. Knudsen LB. Legally induced abortions in Denmark after Chernobyl. Biomed Pharmacother 45:229–231 (1991).
45. Czeizel AE. Incidence of legal abortions and congenital abnormalities in Hungary. Biomed Pharmacother 45:249–254 (1991).
46. Haeusler MCH, Berghold A, Schoell W, Hofer P, Schaffer M. The influence of the post-Chernobyl fallout on birth defects and abortion rates in Austria. Am J Obstet Gynecol 167:1025–1031 (1992).
47. Harjulehto T, Rahola T. Suomela M, Arvela H, Saxen L. Pregnancy outcome in Finland after the Chernobyl accident. Biomed Pharmacother 45:263–266 (1991).