Radiat Environ Biophys (2010) 49:57–65
DOI 10.1007/s00411-009-0246-8

ORIGINAL PAPER

Pregnancy outcome of women in the vicinity of nuclear power plants in Taiwan

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Received: 26 February 2009 / Accepted: 19 September 2009 / Published online: 16 October 2009

Abstract The purpose of the study was to investigate whether proximity to nuclear power plants may increase the risk of abnormal pregnant outcomes among the resident women. In this ecological study, data were used from the Health Services Birth Reports Database established by the Bureau of Health Promotion, National Department of Health, Taiwan, in 2001–2004. Chi-square-tests were carried out to investigate the "Plant-vicinity" and "Non plant-vicinity" group in terms of pregnancy outcome. Additionally, logistic regression was performed to investigate whether residence in the vicinity of a nuclear power plant was related to any abnormal pregnancy results. Based on data from 5,679 included subjects, no difference was observed between pregnancy outcomes of the "Plant-vicinity" and "Non plant-vicinity" groups. After accounting for possible confounders, the adjusted odds ratios were 1.20 (95% CI = 0.56–2.56) for stillbirth, 1.21 (95% CI = 0.95–1.53) for premature birth, 1.04 (95% CI = 0.79–1.37) for low birth weight, and 1.58 (95% CI = 0.85–2.93) for congenital deficiencies, respectively, when comparing the "Plant-vicinity" with the "Non plant-vicinity" group. The results of the study indicate that residence in the vicinity of a nuclear power plant is not a significant factor which will cause abnormal health situations during pregnancy.

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Introduction

The issue of whether low doses of ionizing radiation are beneficial or harmful to health is an unresolved, controversial issue. Given the use of ionizing radiation for medical therapy, the increasing demand for electricity, new research results in radiation epidemiology, and recurrent nuclear power plant incidents, the public has both expectations and fears regarding ionizing radiation.

The influence of ionizing radiation on health generally falls within three categories: carcinogenesis, teratogenesis, and mutagenesis (Guan and Cheng 1988). The present study devotes primarily to an examination of the teratogenetic effects of ionizing radiation. A review of previous studies showed that exposure to ionizing radiation during pregnancy could result in the following effects: (1) delayed growth of fetus in the womb; (2) fetus or new-born death; (3) congenital teratogenesis; (4) increase in frequency of serious disease in childhood; (5) effects on child intelligence and physical development; (6) other effects not directly but indirectly caused by ionizing radiation may include increases in both induced and spontaneous miscarriages and decreases in birth rates (Mole 1979; Guan and Cheng 1988; Dummer et al. 1998; Wang et al. 1999; Doyle et al. 2000; Lee 2000; Auvinen et al. 2001). Several factors including the stage of fetal development at which exposure takes place, the duration of exposure, and the radiation dose, showed some influence on the symptoms observed after exposure. Note that most of these effects were observed after *acute* exposure, including exposure as a part of medical diagnosis or treatment, and nuclear incidents (Otake et al. 1990). *Chronic* low-dose exposure such as radiation fallout (Chernobyl accident caused radiation doses up to 1 mSv during the first year in the Western European countries) may also result in abnormal pregnant outcome (Auvinen et al. 2001). However, there is yet no evidence indicating or proving that ionizing radiation posed a danger to health (Mole 1979; Dummer et al. 1998; Doyle et al. 2000).

Taiwan currently has three nuclear power plants, two in the north (Shih-men Village and Wan-li Village, both located in Taipei County), and one in the south (Heng-chun Township in Pingtung County) (Fig. 1). These plants began operating in 1978, 1981, and 1984, respectively, and cover 20–40% of the national electricity consumption. As a result, they have significantly alleviated the pressure associated with the year-by-year increase in electricity demand. Since 1974, the official Atomic Energy Council of Taiwan is monitoring the health effects of the peaceful application of radioactive substances on the Taiwanese population, and a radiation-monitoring network was constructed in the surroundings of nuclear facilities (Taiwan-Power-Company Nuclear Safety Information System). Since 1991, the Radiation Monitoring Center (a subsidiary government agency under the Atomic Energy Council) has designed and developed many other representative sites to monitor the environment on a routine basis and collect relevant radiation data. Anyone can get 24-h real-time information from its website (http://www.trmc.aec.gov.tw). Based on the monitoring results, the exposure level at each site is found to be lower than 0.2 μSv/h, which means there is no difference between areas close to and far from nuclear power plants. However, anti-nuclear demonstrations reveal that the public is still worrying about the potential health effects caused by nuclear power plants, especially for pregnant women.

As of today, although there have been several epidemiological surveys on health effects in Taiwan (Chen 1990; Lin 1993; Yang 1993; Wu 1997), there is still very little research available on pregnancy health outcome among women living in the vicinity of nuclear power plants. The purpose of this study is to analyze data from the Health Services Birth Reports Database, to understand the health situation of pregnant women and newborn infants living in close to nuclear power plants. The results of this study can serve as a reference in policy-making and as a basis for discussing risks with the public.

Materials and methods

Study areas

The study areas include townships were nuclear power plants are located, and their surroundings consist of two groups: plant vicinity and non-plant vicinity. The "Plant-vicinity" group includes pregnant women in the Shih-men, San-chih, Wan-li and Chin-shan villages in the Taipei county; and the Heng-chun Township in the Pingtung County. The "Non plant-vicinity" group was chosen based on the Taipei County General Development Plan and the Pingtung County Revised General Development Plan. This group includes the Gong-liao, and Shuang-si villages in the Taipei County, and the Che-cheng village in the Pingtung County (Fig. 1). Both groups are coastal and rural areas with higher proportion of emigration. The population density is generally below 1,000/km^2. Agriculture and fishery are the main industries of these areas. Both groups also include townships with similar demographic characteristics, geographical environments, and social and economic development.

Information was collected from individual birth records of pregnant women and their children, for 2001 to 2004 (see "Data sources" below). Because we did not only analyze individual information from the above database but also included the corresponding radiation data from the surrounding environment, the present study is of semi-individual nature, which was considered a valid design as compared with traditional ecologic studies (Kunzli and Tager 1997). The maximum distance from a nuclear power plant in the "Plant-vicinity" group was 14.23 km, and the minimum distance from a nuclear power plant in the "Non plant-vicinity" group was 22.76 km. Based on the radiation monitoring results, there was no difference in exposure level between the "Plant-vicinity" group and "Non plant-vicinity" group.

Data sources

To investigate whether residence in the vicinity of a nuclear power plant may affect pregnancy outcomes of local women, we carried out a cross-sectional study by using the Health Services Birth Reports Database compiled by the Bureau of Health Promotion, National Department of Health and analyzing data from the years 2001–2004. In Taiwan, services related to child delivery are free for all women covered by the National Health Insurance. Therefore, almost all pregnant women chose to give birth in hospitals or clinics (Wu and Young 1986). Because birth certificates are mandatory and being completed by physicians attending the delivery, the data can be considered as complete, reliable, and accurate.

Study subjects

The individuals included in the present study were pregnant women listed in the database in those eight villages (townships) mentioned above. In order to account for the fact that the actual places of residence of these individuals may differ from those listed in their household registry, the

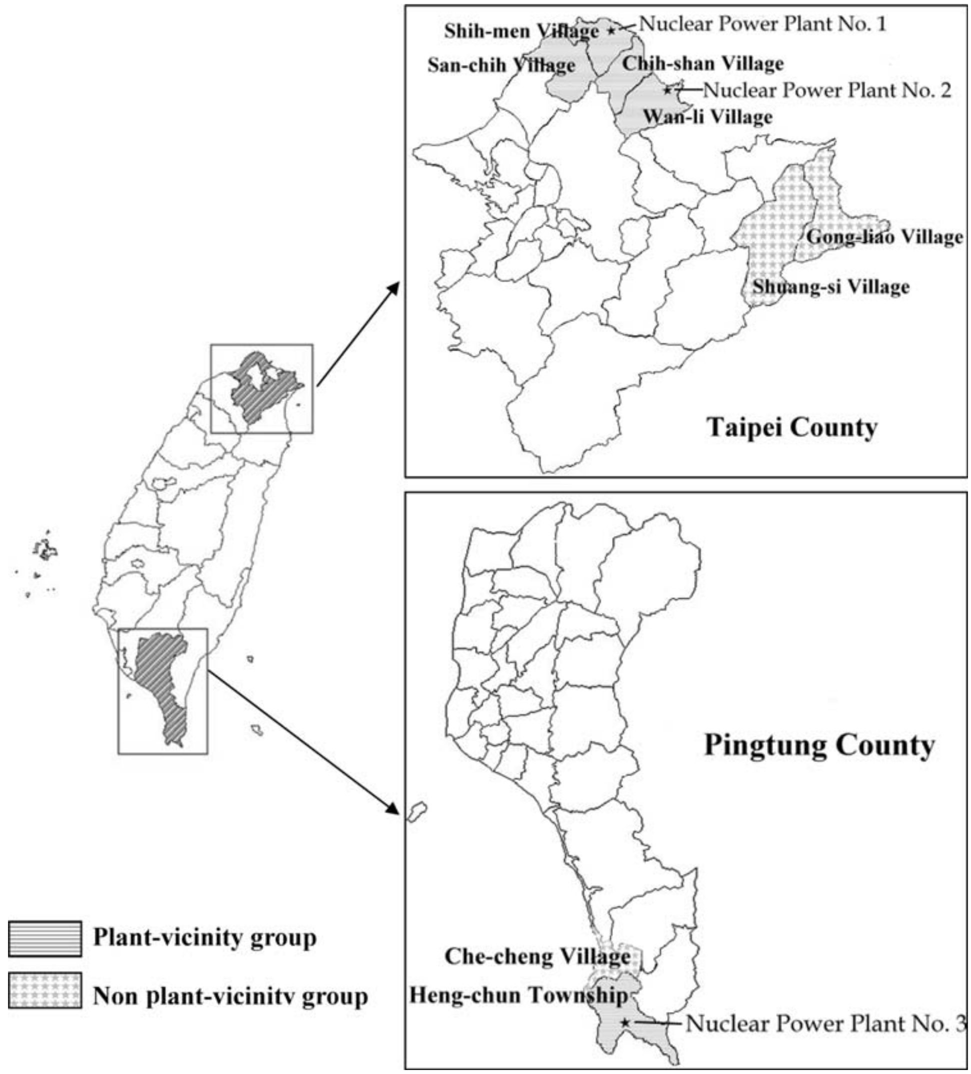

Fig. 1 Study area in Taiwan

individuals were selected based on their current residence, rather than on that given in the household registry.

Data analysis

Chi-square-tests were used to analyze the distribution of the "Plant-vicinity" and "Non plant-vicinity" groups in terms of other variables. Additionally, logistic regression was performed to analyze which factors might influence abnormal pregnancy outcomes. Four of these outcomes were included in the present study: stillbirth, defined as fetal death occurring after 20 weeks of pregnancy; premature birth, defined as childbirth occurring earlier than 37 completed weeks of gestation; low birth-weight, defined as infants born at weight less than 2,500 g; and congenital deficiencies, as identified by professional gynecologists. All data were analyzed using the SPSS 13.0 software package (SPSS Inc. Chicago, Illinois). A P value of <0.05 was considered to indicate a statistically significant result.

Results

In total 5,679 individuals were included in the analyses, with 4,491 in the "Plant-vicinity" group, and 1,188 in the "Non plant-vicinity" group (Table 1). A further description based on three stages of pregnancy is given below.

Pregnancy stage

The average age of pregnant women in the "Plant-vicinity" group was 31.22 years, while that in the "Non plant-vicinity" group was 30.79 years. In the "Plant-vicinity" group, 0.22% of the pregnant women were less than 20 years of age at birth ("underage pregnant women"), while 24.03% were 35 years or older; in the "Non plant-vicinity" group, the corresponding figures were 0.08 and 22.31%, respectively. For women in the "Plant-vicinity" group, average gestation period was 38.24 weeks, while that in the "Non plant-vicinity"

Table 1 Parameters characteristic for the studied cohort (“Plant-vicinity” and “Non plant-vicinity” groups)

	Plant-vicinity ($N = 4{,}491$)		Non plant-vicinity ($N = 1{,}188$)		P value
	N	%	N	%	
Pregnancy status					
Maternal age (years at birth)					0.282
<20	10	0.22	1[a]	0.08	
20–34	3,402	75.75	922	77.61	
≧35	1,079	24.03	265	22.31	
Gestation period (weeks)					0.091
<37	435	9.69	96	8.08	
≧37	4,056	90.31	1,092	91.92	
Health status during pregnancy					0.799
Poor[b]	323	7.19	88	7.41	
Healthy	4,168	92.81	1,100	92.59	
Labor status					
Special measures during pregnancy or labor					0.406
Yes	980	21.82	246	20.71	
No	3,511	78.18	942	79.29	
Delivery method					0.468
Natural birth	2,955	65.80	795	66.92	
Cesarean birth	1,536	34.20	393	33.08	
Labor complications					0.059
Yes	828	18.44	191	16.08	
No	3,663	81.56	997	83.92	
Newborn status					
Newborns birth condition					0.370
Live birth	4,444	98.95	1,179	99.24	
Still birth	47	1.05	9	0.76	
Birth weight of newborns (g)					0.514
<2,500	399	8.88	93	7.83	
2,500–4,500	4,085	90.96	1,093	92.00	
>4,500	7	0.16	2[a]	0.17	
1st minute APGAR score					0.356
<7	107	2.38	34	2.86	
≧7	4,297	95.68	1,136	95.62	
Missing value	87	1.93	18	1.51	
5th minute APGAR score					0.094
<7	34	0.75	15	1.26	
≧7	4,044	90.05	1,065	89.65	
Missing value	413	9.20	108	9.09	
Congenital deficiencies					0.120
Yes	73	1.63	12	1.01	
No	4,418	98.37	1,176	98.99	

[a] Cells (16.7%) have expected counts less than 5

[b] Pregnant woman with some specific health problems during pregnancy (e.g. gestational diabetes mellitus, toxemia of pregnancy, cervical incompetence, …)

group was 38.38 weeks. For both groups, miscarriages (below 20 weeks) or premature birth (20–36 weeks) was less than 10%. Over 90% of these women had no specific health problems during their pregnancy. Of those women who did report specific health problems, the most common problem was anemia (148 cases corresponding to 40.44% in the “Plant-vicinity” group, and 47 cases corresponding to 48.45% in the “Non plant-vicinity” group). There was no significant difference between both groups, in terms of pregnancy status.

Labor stage

Special measures for the mothers' or fetus' health were taken for about 20% of the individuals, in both groups; the most frequent measures were ultrasound and fetal heartbeat monitoring. Because these two measures became standard procedures under Taiwan's national health insurance coverage for prenatal examinations after 2001, this item was no more included in the database since 2002. In terms of delivery methods, over 60% of the women adopted natural (spontaneous) delivery (2,955 cases in the "Plant-vicinity" and 795 cases in the "Non plant-vicinity" group). Approximately, 80% of the women did not experience any complications during parturition. For those in the "Plant-vicinity" group who did experience complications, these were primarily obstetrical emergencies (18.96%), malpresentation (17.29%), and premature rupture of the membrane (10.73%). The situation was similar for those in the "Non plant-vicinity" group. There was no significant difference between both groups, in terms of labor status.

Newborn stage

From 2001 to 2004, the crude birth rate for both groups showed a declining trend—similar to that of the national birth rate—with the rate for the "Non plant-vicinity" group being always lower than that of the other group (Fig. 2). Ninety-nine percent of the newborn infants were live births, in both groups. The rate of stillbirths also declined, representing improvement in Taiwan's public health. The average weight of newborn infants in the "Plant-vicinity" group was 3,066.75 g, while that in the "Non plant-vicinity" was 3,092.95 g. In both groups, over 90% of the newborn infants fell into the normal range of birth weights (2,500–4,500 g).

The database also included the APGAR score for newborn infants. This was the standard used to evaluate the health of newborn infants, consisting of five easily judged criteria. The first minute APGAR score reflects whether or not the newborn infant requires emergent medical treatment. Seven points or more indicates that the infant is in good health, less than seven points indicates that the lung function is impaired. In both investigated groups, the first minute APGAR score was 7 points or higher for 95.68 and 95.62%, respectively; only 2.38 and 2.86% of the newborns had scores below 7. Research described in Drage et al. (1964) indicated that the fifth minute APGAR score shows the closest correlation with newborn death rate. When the first minute score was below 7 and the fifth was more than 7, this reflected the effectiveness of emergency treatment. The fifth minute APGAR score was 7 or more for nearly 90% of the infants in both groups, but missing values were much higher than for the first minute score (9.20 and 9.09%). This may be because the medical facilities would not pay much attention to record the fifth minute score if the newborns' first minute APGAR score was 7 or higher. For both groups, infants born with congenital deficiencies composed 1% of the total. The more frequently appearing congenital deficiencies in the "Plant-vicinity" group were classified as "other" (28 cases, 35.44% of the total deficiencies), respiratory system deficiencies (13 cases, 16.46% of the total), and bone and muscular system deficiencies (10 cases, 12.66% of the total). In the "Non plant-vicinity" group, bone and muscular system deficiencies were the most common (5 cases, 38.46% of the total) followed by "other" (4 cases, 30.77% of the total) and urinary system deficiencies (3 cases, 23.08% of the total). No significant difference was observed between the "Plant-vicinity" and the "Non plant-vicinity" group, in terms of newborn status.

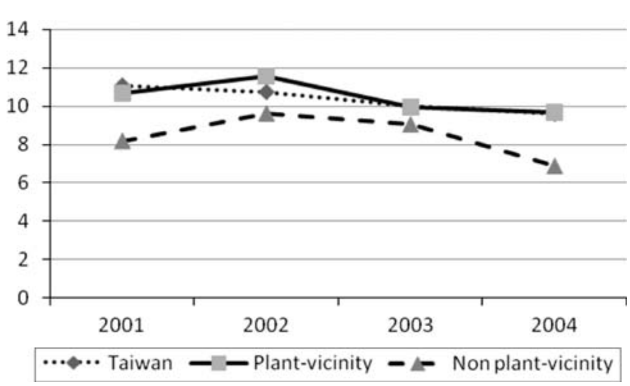

Fig. 2 Crude birth rates

Abnormal pregnancy events

Multicollinearity can cause unstable estimates and inaccurate variances, which both may affect confidence intervals and hypothesis tests (Horel and Kennard 1988). Before starting the analyses, we therefore analyzed the correlations among the independent variables. The results indicated that these were less than 0.4, suggesting that any correlations among variables that might exist were not serious.

Tables 2, 3, 4, and 5 show the results of the Logistic Regression analyses for stillbirths, premature births, low birth-weight, and congenital deficiencies. After correcting for possible confounders (including maternal age, gestation period, maternal health status, special measures taken, and delivery method), the adjusted odds ratios were 1.20 [95% confidence interval (CI) = 0.56–2.56] for stillbirth with a statistical power of 0.79; 1.21 (95% CI = 0.95–1.53; power 0.83) for premature birth; 1.04 (95% CI = 0.79–1.37; power 0.09) for low birth weight; and 1.58 (95% CI = 0.85–2.93) for congenital deficiencies with a statistical power exceeding 0.99 when comparing the "Plant-vicinity" with the "Non plant-vicinity" group.

The model for stillbirth showed a Nagel Kerke R^2 of 0.399 (model fit: −2 Log likelihood = 386.291; $\chi^2 = 19.080$; $P = 0.008$), that for premature birth an R^2 of 0.034 (model fit: −2 Log likelihood = 3347.177; $\chi^2 = 5.039$; $P = 0.539$), that for low birth weight an R^2 of 0.351 (model fit: −2 Log likelihood = 2382.673; $\chi^2 = 9.353$; $P = 0.228$), and that for congenital deficiencies an R^2 of 0.107 (model fit: −2 Log likelihood = 794.941; $\chi^2 = 6.805$; $P = 0.339$). Some of the models did not fit well from the statistical point of view.

Discussion and recommendations

The present study used 4 years of data from the Health Services Birth Reports Database, to assess whether or not residence in the vicinity of a nuclear power plant may affect pregnancy outcomes of local women. For the investigated pregnancy outcomes, no statistically significant differences between the "Plant-vicinity" and the "Non plant-vicinity" group were found. In addition, the study also examined correlating factors for several types of abnormal pregnancy outcomes, including stillbirth, premature birth, low birth weight, and congenital deficiencies. The results showed that these abnormal outcomes were not related to the residence in the vicinity of a nuclear power plant.

Most of the results obtained in the present study compare well with those found in other studies (Harjulehto et al. 1989; Lie et al. 1992; Dummer et al. 1998; Doyle et al. 2000). They are also consistent with the statement of the United States National Council on Radiation Protection and Handling that "when exposure is less than 0.05 Gy (5 rads), compared with the other risks of pregnancy, radiation induced risk can be ignored." (National-Council-on-Radiation-Protection-and-Measurements 1971). The interesting finding of our research is that the crude birth rate for the "Plant-vicinity" group is higher than the "Non plant-vicinity" group, which is inconsistent with the results of similar studies abroad (Auvinen et al. 2001). The partial reason may come from the government subside policy and it needs more evidence to confirm in the future study.

The results also show that the mother's age is a risk factor for abnormal pregnancy outcomes. After correcting for possible confounders, the adjusted odds ratios are 20.89 (95% CI = 2.22–196.61) for stillbirth, 4.58 (95% CI = 1.18–17.70) for premature birth, and 1.08 (95% CI = 0.16–7.46) for low birth weight, when comparing women less than 20 years of age with those 20–34 years of age. Based on these results, public information campaigns should inform young women about the elevated risk of stillbirth and premature birth for mothers below the age of 20.

In addition, this study also found that women with Cesareans section had fewer abnormal outcomes than those with natural delivery. This may be because miscarriage or

Table 2 Predictors of stillbirth deduced by logistic regression ($n = 5,679$)

Variables	Crude OR	Adjust OR	95% CI	P value
Residence				
Non plant-vicinity (reference)				
Plant-vicinity	0.72	1.20	(0.56–2.56)	0.640
Maternal age				
20–34 years old (reference)				
<20 years old	28.04	20.89	(2.22–196.61)	0.008
≧35 years old	1.91	1.80	(0.99–3.28)	0.054
Gestation period				
≧37 weeks (reference)				
<37 weeks	109.29	118.05	(46.44–300.09)	<0.001
Health status during pregnancy				
Healthy (reference)				
Poor	2.83	1.49	(0.69–3.22)	0.311
Special measure				
No (reference)				
Yes	1.59	0.91	(0.48–1.71)	0.765
Delivery method				
Natural birth (reference)				
Cesarean birth	0.37	0.23	(0.11–0.49)	<0.001

Hosmer and Lemeshow Goodness-of-Fit Test = 19.080 ($P = 0.008$)

Table 3 Predictors of premature birth deduced by logistic regression ($n = 5{,}679$)

Variables	Crude OR	Adjust OR	95% CI	*P* value
Residence				
Non plant-vicinity (reference)				
Plant-vicinity	1.23	1.21	(0.95–1.53)	0.121
Maternal age				
20–34 years old (reference)				
<20 years old	4.02	4.58	(1.18–17.70)	0.028
≧35 years old	1.24	1.11	(0.90–1.37)	0.336
Health status during pregnancy				
Healthy (reference)	2.12	1.79	(1.34–2.38)	<0.001
Poor				
Special measure				
No (reference)				
Yes	1.96	1.85	(1.52–2.27)	<0.001
Delivery method				
Natural birth (reference)				
Cesarean birth	1.57	1.59	(1.31–1.91)	<0.001

Hosmer and Lemeshow Goodness-of-Fit Test = 5.039 ($P = 0.539$)

Table 4 Predictors of low birth weight deduced by logistic regression ($n = 5{,}679$)

Variables	Crude OR	Adjust OR	95% CI	*P* value
Residence				
Non plant-vicinity (reference)				
Plant-vicinity	1.15	1.04	(0.79–1.37)	0.802
Maternal age				
20–34 years old (reference)				
<20 years old	2.48	1.08	(0.16–7.46)	0.937
≧35 years old	1.23	1.09	(0.85–1.41)	0.495
Gestation period				
≧37 weeks (reference)				
<37 weeks	32.24	30.96	(24.69–38.80)	<0.001
Health status during pregnancy				
Healthy (reference)				
Poor	2.00	1.33	(0.92–1.92)	0.130
Special measure				
No (reference)				
Yes	1.62	1.11	(0.86–1.43)	0.438
Delivery method				
Natural birth (reference)				
Cesarean birth	1.36	1.12	(0.89–1.40)	0.351

Hosmer and Lemeshow Goodness-of-Fit Test = 9.353 ($P = 0.228$)

premature births are usually reported as natural delivery. It strengthens the link between natural delivery and abnormal pregnancy outcomes.

However, there are several limitations that need to be mentioned. The Health Services Birth Reports Database is compiled using the reports filed by medical institutions through the On Line Birth Report Data Transmission System. It cannot reflect situations when a pregnancy is terminated due to illness or malformation. And related interfering factors such as smoking, drinking, nutrition status, and social status, might also influence abnormal pregnancy outcomes. Mobility during pregnancy is likely to be another uncontrolled variable in this study: No data are available in this respect, but influence of mobility is probably minor, since actions such as moving heavy family furniture, using sharp objects such as scissors, or migrating are usually

Table 5 Predictors of congenital deficiencies deduced by logistic regression ($n = 5{,}679$)

Variables	Crude OR	Adjust OR	95% CI	*P* value
Residence				
Non plant-vicinity (reference)				
Plant-vicinity	1.62	1.58	(0.85–2.93)	0.152
Maternal age				
20–34 years old (reference)				
<20 years old	–	–	–	–
≧35 years old	1.06	0.93	(0.56–1.55)	0.771
Gestation period				
≧37 weeks (reference)				
<37 weeks	2.86	2.11	(1.23–3.62)	0.007
Health status during pregnancy				
Healthy (reference)				
Poor	7.07	4.96	(3.05–8.05)	<0.001
Special measure				
No (reference)				
Yes	4.01	2.82	(1.79–4.44)	<0.001
Delivery method				
Natural birth (reference)				
Cesarean birth	0.63	0.61	0.37–1.01)	0.054

Hosmer and Lemeshow Goodness-of-Fit Test = 6.805 ($P = 0.339$)

being avoided during pregnancy, because the Chinese population believes these actions to be harmful for unborn babies (Chinese-Folk-Culture-Website http://www.chinesefolkculture.com/info_view.asp?id=1313). The number of children per mother may be another important risk factor for pregnancy outcome, but currently there is no related information available. Data about infants who died within a week after birth could also not been incorporated in the present study. These data are kept in the Death Records File and can be included in a future study.

Due to limitations of the database content, the percentage of variance in the data that could be explained is low, and the model used to describe premature birth and congenital deficiencies did not fit well. It may well be that more factors than those included in the present study influence abnormal pregnancy outcomes (Vorherr 1982; Li and Fu 2001) including hereditary factors, maternal environmental effects, and external environmental factors, greatly increasing the complexity and difficulty of the researcher's task. Follow-up studies should consider the use of additional tools such as questionnaires and interviews, to compensate for the limitation to use secondary data. Some abnormal pregnancy outcomes are not apparent at birth or even during infancy. For instance, brain injuries might not be discovered until later in childhood (Mole 1979). It is, therefore, suggested that any follow-up studies should also focus on fetal deaths during pregnancy, congenital abnormalities in newborns, and delayed mental development during later childhood and adolescence.

Given the problem of global warming becoming more and more serious, and the continual increase in domestic demand for energy, nuclear power is an option. In order to ease the fears of those living in the vicinity of nuclear power plants, official and scientific institutions should make more efforts to investigate any health effects on humans exposed to low doses of ionizing radiation.

Acknowledgments Both the present study and the data source used are sponsored by the Bureau of Health Promotion, National Department of Health, Taiwan (BHP94-CH3-001). The findings and conclusions in this article are those of the authors, who are responsible for its content, and do not necessarily represent the views of Bureau of Health Promotion, National Department of Health, Taiwan. We also like to acknowledge the anonymous reviewers who made valuable suggestions during the peer-review process.

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