Nuclear Energy: Danger Only in Case of Accidents?

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Abstract

The environmental impacts of nuclear energy are highly underestimated. Nuclear weapons, atomic bomb tests, and nuclear accidents are considered a danger for the environment and a human cancer risk. However, childhood leukemia is consistently elevated near nuclear power plants and the Chernobyl accident entailed elevated human birth sex ratios across Europe. We studied the annual sex ratio near nuclear facilities in Germany, France, and Switzerland at the municipality level. We will demonstrate that low doses of ionizing radiation cause effects in human beings. This is shown by strongly consistent spatial-temporal shifts in the human sex ratio trends in the vicinity of nuclear facilities. In the chosen countries complete official data on over 70 million gender specific annual births at the municipality level are available. By Lambert-93 coordinates (France) and GK3 coordinates (Germany, Switzerland) we determined the minimum distances of municipalities from major nuclear facilities. Spatial-temporal trend analyses of the annual sex ratio depending on municipalities' minimum distances from nuclear facilities were carried out. Applying ordinary linear logistic regression (jump or broken-stick functions) and non-linear logistic regression (Rayleigh functions) we demonstrate that the sex ratio at birth shows the influence of mutagenic ionizing radiation on human health. As important environmental chemical contaminants are also mutagenic, the usefulness of the sex ratio at birth as a genetic health indicator can be inferred by analogy.

1. Introduction

Nuclear energy supplied 11% of global electricity production in 2011. Three countries draw more than half their electricity from nuclear plants (France leads at 78%, followed by Slovakia and Belgium at 54% each), and ten additional countries, all but one in Europe, draw more than 25% from this source [1]. For example, the running 58 French nuclear reactor blocks generate 78 percent of the entire country's electricity, and France is also the largest exporter of nuclear electricity in the European Union. France is second in the world (behind the United States) in terms of total nuclear power production, contributing 16 percent of the world's nuclear electricity. The risks of a catastrophic impact on the environment and human health by nuclear power plant accidents are evident and well documented. The modelling results by Lelieveld et al. [2] indicate that previously the occurrence of INES 7 major accidents and the risks of global radioactive contamination have been underestimated. Hence high human exposure risks occur around reactors in densely populated regions, notably in West Europe and South Asia, where a major reactor accident can subject around 30 million people to radioactive contamination. The recent decision by Germany to phase out its nuclear reactors will reduce the national risk, though a large risk will still remain from the reactors in neighboring countries. Furthermore, many nuclear facilities are 30-45 years old.

The health consequences among populations living near nuclear facilities have been feared and in some countries extensive and expensive studies have been performed concerning e.g. childhood cancer and childhood leukemia. A meta-analysis of standardized incidence and mortality rates of childhood leukemia in proximity to nuclear facilities has been carried out [3]. It was stated that the majority of those ecological studies found elevated rates of childhood leukemia, although usually

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not statistically significant. Case-control studies on cancer and leukemia in young children were performed in Germany [4, 5], in Switzerland [6], in Great Britain [7], and in France [8]. Although the authors remained vague in general (weak evidence, possible confounding, no causal relation), in most studies concern was raised over an increased general human health risk in the vicinity of running nuclear facilities. Our previous work [9, 10] provides considerable evidence that not only after serious nuclear accidents but also near normally running nuclear power plants and especially near nuclear processing and storage sites, the human sex ratio at birth is distorted and in some places to a rather large extent.

2. Sex Odds as an Indicator of Genetic Health

According to Neel and Schull [11], the sex ratio, or in technical/mathematical terms sex odds, is unique among the genetic indicators. Its uniqueness arises from the fact that maternal exposure is expected to produce sex odds different from sex odds after paternal exposure. Therefore, the odds of male to female offspring at birth may be a simple and non-invasive way to study and monitor the reproductive status or reproductive health of a population. According to Scholte and Sobels [12], one of the few methods available for studying the genetic effects of ionizing radiation in man is the observation of changes in the sex odds among offspring from irradiated parents. Lethal factors of varying degree of dominance on the X chromosome, depending on whether an impaired X chromosome is derived from the mother or the father, impact the formation and the survival probability of the female zygote, entailing more or less girls at birth. According to theory, Cox found a reduced offspring sex ratio in irradiated women, and James, on the other hand, states, “ionizing radiation is the only reproductive hazard, which causes” (irradiated) “men to sire an excess of sons” [13-15]. In addition to lethal factors on the X chromosome, Scholte and Sobels [12] allude to nondisjunction resulting in X0 genotypes, which are non-viable in man and, thus, may also distort the birth sex odds. Except in societies where selective abortion skews the sex odds, approximately 104 to 106 boys are born for every 100 girls. In humans, on the one hand, the sex odds at birth is constant at the secular population level [16], but on the other hand, considerable variability may be observed under a variety of specific circumstances. A lot of hypothetical sex odds determinants, among them race and season, and methodological challenges assessing those determinants have been discussed in the literature [17]. Steiner [18] points out that proposed determinants often showed associations in small samples that could not be replicated in larger populations. This, of course, may be due to insufficient statistical power due to small effects and/or small study-populations.

Anthropogenic chemicals and ionizing radiation are determinants of the human secondary sex odds at birth. From animal experiments it has been known for long that exposure to mutagenic chemicals or ionizing radiation can alter the natural sex odds of living beings [19-21]. Stevenson and Bobrow [22] provide a detailed account of methodological issues relevant for the assessment of determinants of the sex odds in man with special emphasis on the impact of male fetal mortality dynamics on the sex odds. Terrell et al. [23] reviewed approximately 100 publications on possible environmental and occupational determinants of the sex ratio. They concluded: “Limitations in study design and methodological issues make it difficult to draw firm conclusions from the existing sex ratio literature”. This highlights the difficulties in generating firm knowledge on sex odds determinants in man. Since recently, we put research emphasis on the effect of chemicals on the human secondary sex odds. In our first evaluation approach around chemical plants, we considered the influence of chemical accidents on the sex odds. We took a closer look at the live birth sex odds in the vicinity of Hoechst-Griesheim, where an accident occurred in 1993 spreading tons of nitroarenes into the environment [24]. Here, we detected a remarkable decrease in the sex odds after the chemical accident [25]. Sociological influences, like e.g. stress, have also been reported.

We just name the sex odds studies after earthquakes in Chile [26] and Italy [27]. In accordance with the Trivers-Willard hypothesis [28], the results of these studies suggest decreases of the human sex ratio at birth under adverse living conditions. However, the most dramatic influence on the sex ratio is man-made, namely sex selective abortion, which poses a problem for example in China and in India [29, 30].

3. Data and Statistical Methods

Complete annual gender specific birth data at the municipality level from 1968 (minimum) till 2013 (maximum) were provided by French, German, and Swiss national statistical authorities. Data were processed with SAS and stored in a data base composed of several SAS data sets. The characteristics and geographical positions of the investigated running and closed nuclear power plants was obtained from the comprehensive documentation by the IAEA "International Atomic Energy Agency" nuclear power plant information system (http://www.iaea.org/pris/home.aspx). For geo-coding municipalities and nuclear facilities in the German and Swiss evaluation studies geographic coordinates given in the Gauss–Krüger coordinate reference system (CRS) are used. For France, we used Lambert-93. Lambert-93 is a projected CRS that is suitable for use in France - onshore and offshore, mainland and Corsica. Lambert-93 is a CRS for large and medium scale topographic mapping and engineering survey. It was defined by information from IGN – Paris, "Institut national de l'information géographique et forestière" (http://www.ign.fr/). Lambert-93 is well suited for our purpose of determining the distances of municipalities from nuclear facilities in France. To assess time trends in the occurrence of boys among all live births, and to investigate whether there have been changes in the trend functions after distinct events, we applied ordinary linear logistic regression. This involves considering the male proportion among all male (m) and female (f) births: $p_m = m/(m+f)$. Important and useful parameters in this context are the sex odds: $SO = p_m/(1- p_m) = m/f$, and the sex odds ratio (SOR), which is the ratio of two interesting sex odds if those two sex odds have to be compared, e.g. in exposed versus non-exposed populations. We used dummy coding for single points in time and for time periods as well. For example, the dummy variable for the time window from 2001 on is defined as $d_{2001}(t) = 0$ for $t < 2001$ and $d_{2001}(t) = 1$ for $t \geq 2001$. The simple and parsimonious logistic model for a trend and a jump in 2001 has the following form (LB = live births):

$Boys_t \sim Binomial(LB_t, \pi_t)$:

$$\text{log odds}(\pi_t) = \text{intercept} + \alpha * t + \beta * d_{2001}(t)$$

The data in this study were processed with Microsoft Excel 2003. For statistical analyses, we used R 2.11.1, MATHEMATICA 8.0, and mostly SAS 9.3 (SAS Institute Inc: SAS/STAT User's Guide, Version 9.3. Cary NC: SAS Institute Inc; 2012).

4. Results

As a typical example, we consider the nuclear power plant Philippsburg, Germany. This power plant also operates an interim storage for highly active waste (HAW) from the year 2001 onwards (http://www.bfs.de/de/transport/zwischenlager/dezentrale_zwischenlager/standorte/kkp.html). As we have shown that within 40 km from the HAW storage site in Gorleben the sex odds at birth is distorted [31], it is interesting to look for a similar effect in the more highly populated area around the nuclear power plant at Philippsburg. Figure 1 shows that indeed from 2001 onward the human sex odds at birth trend is subject to a significant jump with a sex odds ratio of 1.026, 95%-CL=[1.009, 1.043], p-value=0.0023. This striking result confirms our corresponding observation at Gorleben [31].

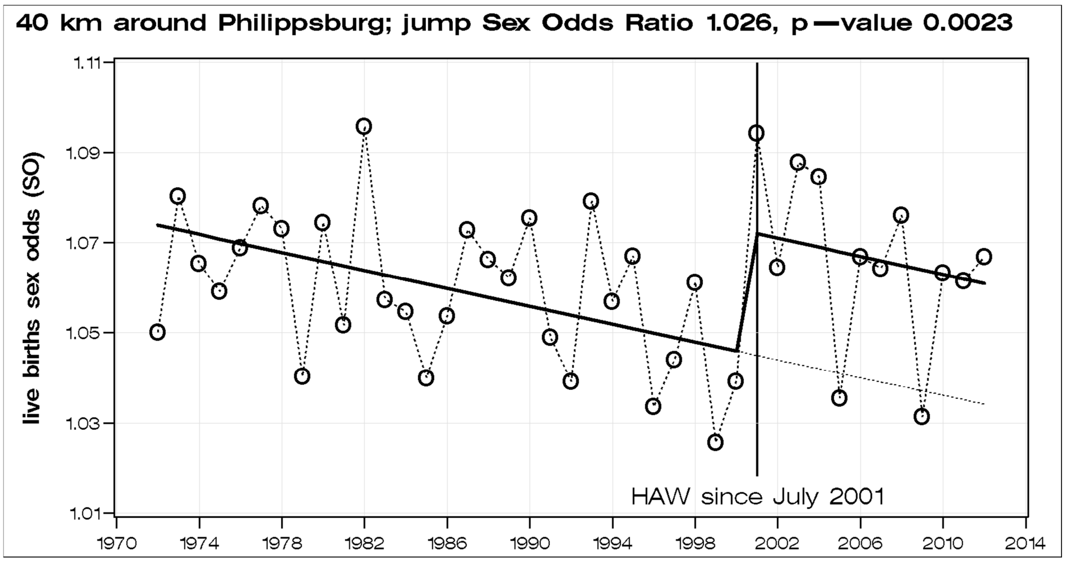

Figure 1: Trend of the human sex odds at birth within 40 km from the HAW storage Philippsburg, Germany

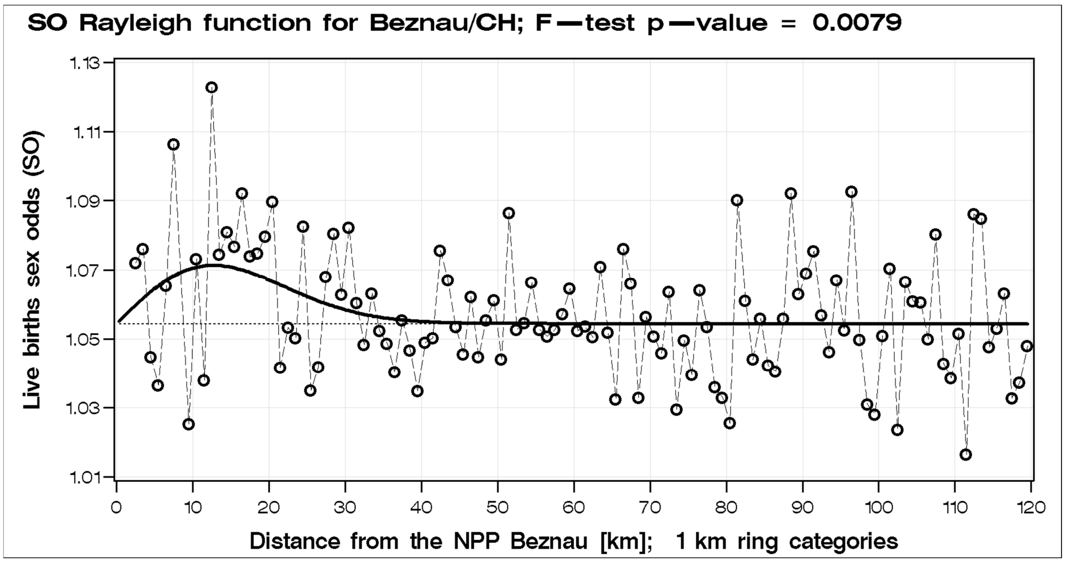

Figure 2: Spatial trend of the sex odds (1969 - 2012) within 1 km distance rings around Beznau in Switzerland (CH)

Figure 2 displays the optimum Rayleigh function for the spatial distance law of the sex odds in Swiss municipalities depending on the proximity to the Swiss nuclear power plant Beznau. The estimated base line sex ratio is 1.0544. The estimated sex odds peaks at 12.7 km (95% CI: 7.8, 17.6) with a SOR_{peak} 1.0161 (95% CI: 1.0043, 1.0281).

As a significantly elevated human sex odds at birth has been found in the vicinity (< 35 km) of nuclear facilities in Germany and Switzerland [9], we tested whether this was also the case in France. In fact, within 35 km from the selected 28 French nuclear facilities listed in Table 1 we also found significantly elevated sex odds. The sex odds ratio SOR for the jump at 35 km distance is 1.0028 (95% CI: 1.0007, 1.0049), F-Test p-value 0.0096, see Figure 3 (l.h.s).

Table 1. French nuclear power plants (n=23) and 5 major nuclear facilities

	Nuclear power plants	Location	Exposure since
1	BELLEVILLE	LENE	1986
2	BLAYAIS	BRAUD ST.LOUIS	1980
3	BUGEY	ST. VULBAS	1971
4	CATTENOM	CATTENOM	1985
5	CHINON	AVOINE	1962
6	CHOOZ	CHARLEVILLE	1966
7	CIVAUX	CIVAUX	1996
8	CRUAS	CRUAS	1982
9	DAMPIERRE	DAMPIERRE-EN-BURLY	1979
10	EL4	BRENNILIS	1966
11	FESSENHEIM	FESSENHEIM	1976
12	FLAMANVILLE	FLAMANVILLE	1984
13	G2/PHENIX	MARCOULE	1958
14	GOLFECH	AGEN	1989
15	GRAVELINES	GRAVELINES	1979
16	NOGENT	NOGENT-SUR-SEINE	1986
17	PALUEL	PALUEL	1983
18	PENLY	PENLY	1989
19	RAPSODIE	CADARACHE	1966
20	ST.ALBAN	SAINT-MAURICE-L'EXIL	1984
21	ST.LAURENT	ST. LAURENT DES EAUX	1968
22	S/PHENIX	CREYS-MALVILLE	1985
23	TRICASTIN	PIERRELATTE	1979
	Nuclear facilites		
24	RESEARCH CENTER	GRENOBLE	1971
25	RESEARCH CENTER	CAEN	1983
26	STORAGE SITE	LUXEUIL	1966
27	URANIUM MINING	KRUTH	1953
28	WASTE DISPOSAL	SOULAINES-DHUYS/CSA	1992

An impartial Rayleigh function, which is based on 3 parameters instead of only 2 parameters for the jump function, and which does not require an arbitrary predefined distance category like 35 km, yields an even more precise result. The overall F-test p-value for the Rayleigh function is 0.0018. The estimated base line sex ratio is 1.0506 (95% CI: 1.0499, 1.0514). The estimated sex odds peaks at 9.1 km (95% CI: 5.8, 12.4) with a SOR_{peak} 1.0084 (95% CI: 1.0036, 1.0132), see Figure 3 (r.h.s). The jump and Rayleigh function analyses are based on all 33,114,626 births in France from 1968 to 2011. These findings essentially mean that within 35 km from the investigated 28 nuclear facilities in France combined, the sex odds is 1.0535 whereas outside of these combined areas, i.e. in the rest of France, the sex odds is 1.0506. If this increase in the sex odds by the factor 1.0028 (sex odds ratio) in the vicinity of nuclear facilities were exclusively due to a deficit in girls, it would correspond theoretically to 5730 (95% CI: 1499, 9982) missing girls in the combined 35 km vicinities of those 28 nuclear facilities. We emphasize that this is most probably a rather conservative estimation of the “real effect” as there are many more nuclear facilities in France not yet investigated, and the effect is probably further ranging than 35 km. The latter can be anticipated from close inspection of Figure 3 (l.h.s): the 50 km range is also significant (data and results not shown). Moreover, we must assume considerable non-differential misclassification biasing our results towards null. There is a great variety of eligible ionizing materials, differing exposure pathways, as well as exposure conditions of susceptible people. Also, as long as we have not identified all relevant nuclear facilities, our control region, i.e. the “rest of France”, is contaminated so to speak. This inevitably entails only a partial reflection of the presumable “real effect”.

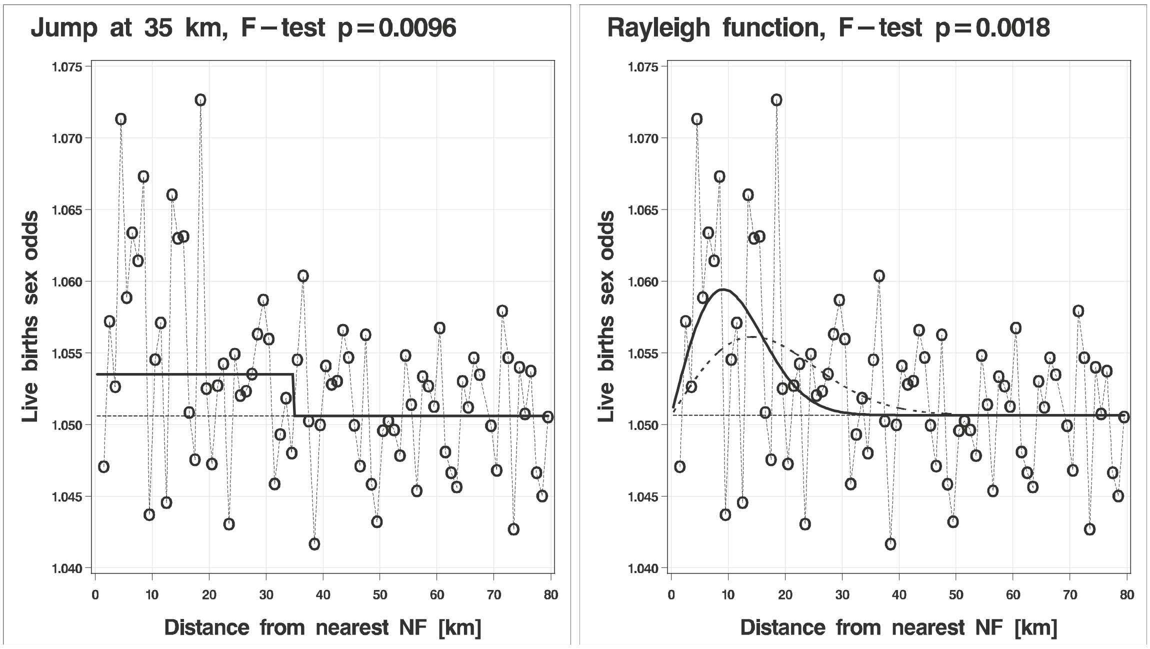

Figure 3: Jump function (35 km, l.h.s.) and Rayleigh function (r.h.s.) for the live births sex odds (male:female) depending on distance form nuclear facilities (NF) in France (Table 1). The broken Rayleigh function (r.h.s.) is the base line adjusted Rayleigh function in Figure 4 by Scherb and Voigt (2011) for Germany and Switzerland combined

5. Discussion

There is little doubt that mutagenic physical and chemical environmental hazards can alter the human sex ratio at birth. We found consistently elevated sex ratios after Chernobyl across Europe, and even in Cuba contaminated foodstuffs from the former Soviet Union presumably caused increases in the sex ratio [10, 32-34]. Recently, based on our findings, Grech [35] has shown that the sex ratio increased in parts of Scandinavia and especially so in the most exposed Norway in the 10-years period following the October 1957 Windscale/Sellafield accident in the United Kingdom. Since childhood cancer and leukemia are elevated near nuclear power plants and increased cancer and increased sex ratio after Chernobyl originate in genetic effects at the molecular and cellular levels, it was a self-evident enterprise to investigate the sex odds in the vicinity of nuclear reactors and more generally near nuclear facilities of all kinds. In fact, based on 20 million annual births in Germany and Switzerland at the municipality level from 1969 to 2009, we found increased sex odds near nuclear power plants and other nuclear facilities [9, 10].

Our temporal and spatial analyses on French nuclear facilities corroborate our previous findings in Germany and Switzerland. There is a small increase of a few per mill in the sex odds around nuclear facilities including nuclear power plants in France. The strength of our approach is the fact that we analyze total national data and no random samples from data. Therefore, sampling error and sampling confounding is not an issue for our studies. A clear weakness of our approach is of course the highly aggregated nature of our data at an annual municipality basis ignoring alternative sex ratio determinants. However, this obvious drawback is perhaps more than outweighed by the sheer amount of individual births data in the tens of millions, the corresponding full registration over decades within all municipalities at a national basis. The last author has investigated the possibility of thermal neutron activation near casks containing highly radioactive waste [36]. According to this analysis, the activation product 41-Argon may play an underestimated role. Another possibility is that fast neutrons (≈1 MeV) at the surface of highly active nuclear waste casks are underestimated with respect to range and biological effectiveness [31]. The possibility of incomplete knowledge in the radiation sciences has recently been stressed in the nuclear accident context: “There may be ‘unknown’ exposure pathways or unsuspected radionuclides, among other factors” [37]. This applies also to normally running nuclear facilities in as much as they emit radiation or radioactive elements insufficiently investigated. Moreover, the authors of the so called French GeoCap study who found increased childhood leukemia near French nuclear power plants stressed the possibility of an unidentified causal radiation factor as there was no obvious association of increased childhood leukemia with measured radiation dose categories (dose-based geographic zoning): “Overall, the results suggest a potential excess risk over 2002–2007 that may be due to unknown factors related to the proximity of NPPs” [8]. In conclusion, we obtained evidence in favor of the existence of an unexpected effect of ionizing radiation on the human secondary sex ratio after nuclear accidents as well as within tens of kilometers from seemingly normally running nuclear facilities of all kinds including nuclear power plants. Further research in this field is urgently needed. We are of the strong opinion that nuclear facilities pose a genetic risk to humans and creature and that more research should be initiated in this respect. Action must be taken to phase out of nuclear power and not to construct new nuclear power plants.

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