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# Modelling human radiation risks around nuclear facilities in Germany and Switzerland: A case study

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## **Abstract:**

Ever since the discovery of the mutagenic properties of ionizing radiation, the possibility of birth sex odds shifts in exposed human populations was considered. The aim of this study was to investigate sex odds trends in the vicinity of nuclear facilities. Official gender specific annual live birth data were compiled at the levels of all municipalities in Germany, Switzerland and France. In a recently published study by the authors, the effect of ionizing radiation on the alteration of sex odds in the vicinity of German nuclear facilities was investigated. The authors revealed an increase in the sex odds. To assess spatial, temporal, as well as spatial-temporal trends in the sex odds and to investigate possible changes in the vicinity of nuclear facilities, we apply ordinary linear logistic regression. In the current study we put emphasis on the explanation of the modelling approach, which is developed for this evaluation of millions of birth statistic data. Furthermore, we add more evidence on the results of an increased sex odds by the evaluation of the surrounding of the TBL Gorleben (Transportbehälterlager: nuclear waste shipping casks storage) in Lower Saxony, Germany. A significant increase in the human sex odds at birth was revealed around Gorleben. Two different models are applied: The simple jump function and the Rayleigh function.

**Keywords:** *sex ratio, nuclear facilities, radiation induced genetic effects, simple jump function, Rayleigh function.*

## **1 INTRODUCTION**

The possibility that radiation releases from nuclear facilities could cause cancer in surrounding populations has been of interest for more than two decades. In April 2010 the U.S. Nuclear Regulatory Commission (NRC) asked the National Academy of Sciences (NAS) to analyze “radiogenic cancer mortality and total cancer mortality in populations living near past, present, and possible future commercial nuclear facilities for all age groups,” and to conduct the same analyses for cancer incidence. Before beginning the full study in late 2011, the NAS is to conduct a scoping study to determine the best study design for assessing risks [Wing et al, 2011]. In Europe several studies have been performed during the past few years. In Germany, a case control study was conducted where cases were children younger than 5 years (diseased between 1980 and 2003) registered at the German childhood cancer registry (GCCR). Residential proximity to the nearest of the 16 German nuclear power plants was determined for each subject individually (with a precision of about 25 m). The study was focused on childhood cancer and whether there was an increasing risk with decreasing distance from the nuclear

plants. A categorical analysis, e.g., showed a statistically significant odds ratio of 2.19 (lower 95%-CL: 1.51) for leukaemia and residential proximity within 5 km compared to residence outside this area [Kaatsch et al., 2008]. Results show an increased risk for childhood cancer less than five years when living near nuclear power plants in Germany [Spix et al., 2008]. In Switzerland, experts investigated the incidence of childhood leukaemia in the vicinity of Swiss nuclear power plants (NPPs). The authors concluded that their nationwide cohort study found little evidence of an association between residence near NPPs and the risk of leukaemia or any childhood cancer [Spycher et al., 2011]. However, the power of this study was insufficient for realistic risk assumptions [Knüsli et al., 2009]. In a recently published French study, childhood acute leukaemia (AL) around 19 French nuclear power plants was investigated from 2002 – 2007. The results suggest a possible excess risk of AL in the close vicinity of French NPPs. The absence of any association with the dose-based geographic zoning may indicate that the association is not explained by NPP gaseous discharges. Overall, the findings call for investigation for potential risk factors related to the vicinity of NPPs, and collaborative analysis of multisite studies conducted in various countries [Sermage-Faure et al., 2012]. Hence, the carcinogenicity of ionizing radiation around nuclear power plants has been investigated in several studies. It has been known for almost one century that ionizing radiation even at low dose (100 mSv) causes mutations [Muller, 1918]. The Nobel Prize in Physiology or Medicine 1946 was awarded to Hermann J. Muller "for the discovery of the production of mutations by means of X-ray irradiation". It was Muller's hypothesis that even background radiation causes mutations. An important indicator in this context is the human sex ratio at birth. Only few ongoing research has been carried out in this area ever since. We have been investigating on the topic of sex ratio/sex odds at birth with respect to ionizing radiation for a couple of years. Sex ratio is the ratio of males to females in a population. In this iEMSs Conference 2012, three contributions are presented concerning the sex odds: one by Kusmierz et al. treating possible data sources/statistical databases that are exploited, the second one by Voigt et al. concerning differences in the human sex odds around chemical plants/parks, and the present paper treating changes in sex odds around nuclear facilities.

## **2 IONIZING RADIATION CAN ALTER HUMAN SEX ODDS**

The ratio of male to female offspring at birth may be a simple and non-invasive way to monitor the reproductive health of a population. Except in societies where selective abortion skews the sex ratio (SR), approximately 105 boys are born for every 100 girls. The authors concluded from a large retrospective cohort study that the sex ratio at birth is remarkably constant [Ein-Mor et al., 2010]. In a systematic review of 100 studies, Terrell et al. [2011] examined whether environmental or occupational hazards alter the sex ratio at birth. The authors took a look at 15 studies on the effect of ionizing radiation on the sex-odds. The studies were classified in the effects of the treatment for childhood cancer and on the effects of occupational ionizing radiation. The number of births exposed ranged from 84 to 39502 which are really very small numbers to be considered for statistical sex odds studies. Only very few research initiatives are published on the influence of ionizing radiation on the human sex odds. In 2009, Scherb and Voigt [2009] published a paper on the trends in the human sex odds at birth in Europe after the Chernobyl Nuclear Power Plant accident. The findings suggest a possible long-term chronic influence of the Chernobyl Nuclear Power Plant accident on the human sex odds at birth in several European countries. In a recently published study [Kusmierz et al., 2010], [Scherb and Voigt, 2011], and [Scherb and Voigt, 2012], the effect of ionizing radiation on the alteration of sex odds in the vicinity of German nuclear facilities was investigated. Within 35 km distance from nuclear facilities, the sex odds increase significantly in the range of 0.30% to 0.40% during nuclear facility operating time. Occasionally available datasets are large but interesting or relevant differences in sex odds are small. For example 100 000 cases are needed to achieve a significant result with a probability of 80% when testing the null sex odds

1.06 against 1.08, and approximately 400 000 cases are required for an 80% power if the 'true' alternative sex odds under exposure were only 1.07. Note that the statistical power is even more reduced in case of a two-sample problem where no reference is made to a 'true' null parameter, but two independent populations are compared instead. Even for 100 000 exposed and 100 000 non-exposed births the power would be only 54% to detect an increase from a normal sex odds of 1.06 to a disturbed sex odds of 1.08. Nevertheless, several hundreds of female conceptuses might be affected detrimentally in such a hypothetical situation under the conservative assumption that only the female gender was susceptible [Scherb and Voigt, 2009]. From this point of view, the paper by Terrell et al. [2011] offers interesting insights. The vast majority of the 100 studies discussed has no more than one thousand (1000) exposed cases, and only four (4) investigations are based on numbers of births between 10 000 and 40 000. With such small numbers it is virtually impossible to generate firm knowledge on sex odds determinants.

### **3 EVALUTION OF NUCLEAR FACILITIES IN GERMANY**

#### **3.1 Geo-spatial background**

For the computation of distances in the German epidemiological study on childhood cancer in the vicinity of nuclear power plants [Spix et al. 2008], geographic coordinates given in the Gauss-Krueger coordinate system are used. The Gauss-Krueger coordinate system is a special transverse Mercator map projection used in Germany, Austria and Finland rather than the Universal Transverse Mercator (UTM)-system but similar to this. The central meridians of the Gauss-Krueger zones are only 3° apart, as opposed to 6° in UTM. A transverse Mercator map projection approximates the reference ellipsoid by a cylinder sector, which perimeter smoothes the central meridian of the mapped zone some depth below the reference surface, so the elliptical cylinder intersects the ellipsoid. The transverse Mercator map projection provides a nearly conformal mapping of earth's surface in smaller regions, so distances can simply be computed by using the Euclidean distance from the numerical differences of the coordinate components with very small errors. The Helvetian Swisstopo uses a special oblique cylindrical Mercator projection with an inclined cylinder axis (also called "Swiss Grid"), based on a double projection starting from the 1841 Bessel ellipsoid and using a fundamental point in Berne. For distance computations over different systems it is necessary to transform coordinates into the same system. For the transformations, online calculators provided by the national geodetic authorities were used. For longer distances (more than some arc degrees) Euclidian distance from cylindrical coordinates causes increasing errors. Therefore, longer distances were computed using spherical trigonometry or, for higher precision, nautical programs.

#### **3.2 Selection of Nuclear Facilities in Germany and Switzerland**

We selected 32 nuclear facilities (NF) in or near the border of Belgium, Germany, and Switzerland for our statistical data analysis (see Table 1). The sites together with the type of site, their period of operation and the given life birth data, sex odds ratio, and p-values are listed in Table 1. Concerning the types of nuclear facilities, it may be distinguished among the following types:

NSS = Nuclear Storage Site  
PWR = Pressurized Water Reactor  
BWR = Boiling Water Reactor  
NFE = Nuclear Fuel Elements  
UM = Uranium Mining Site

We took a look at the gender specific births and sex odds ratio through operational periods within 35 km distance from the NF. Those nuclear facilities marked with an

“\*\*” were not considered because of low Belgium sex odds and low temporal data coverage, i.e., Belgium municipality data are available from 1989 onward only. Also, research reactors have not been taken into consideration in this approach as yet.

**Table 1. 32 Nuclear Facilities in Germany and Switzerland**

NF	Type	In operation since/to	Live births < 35 km during NF operation, lagged for gestation		Sex odds ratio vs. last row of this Table	p-value (Chi <sup>2</sup> )	hold one NF out p-value (Chi <sup>2</sup> ) compare to **
			male	female			
Biblis	PWR	1975 -	223 648	211 753	1.0017	0.5804	0.0007
Obrigheim	PWR	1969 - 2005	164 321	155 447	1.0026	0.4733	0.0010
Neckarwestheim	PWR	1976 -	380 463	360 212	1.0017	0.4640	0.0005
Philipsburg	BWR/PWR	1980 -	333 967	314 761	1.0063	0.0133	0.0019
Grafenreihfeld	PWR	1981 -	95 714	90 722	1.0006	0.8957	0.0007
Isar I und II	BWR/PWR	1977 -	67 059	63 341	1.0041	0.4627	0.0011
Gundremmingen	BWR	1966 -	142 702	135 276	1.0005	0.8986	0.0006
Fessenheim	PWR	1977 -	99 148	93 694	1.0036	0.4290	0.0012
Beznau I und II	PWR	1969 -	337 335	317 880	1.0065	0.0106	0.0031
Goesgen	PWR	1979 -	220 979	208 604	1.0047	0.1308	0.0005
Leibstadt	BWR	1984 -	143 467	135 293	1.0057	0.1354	0.0008
Muehleberg	BWR	1971 -	218 795	207 560	0.9998	0.9387	0.0004
Emsland	PWR	1988 -	55 502	52 301	1.0065	0.2915	0.0011
Grohnde	PWR	1984 -	84 739	80 308	1.0008	0.8791	0.0009
Wuergassen	BWR	1972 - 1994	34 453	32 643	1.0010	0.8960	0.0010
BR*	PWR	1962 - 1987	5 332	5 288	0.9563	-	-
Doel*	PWR	1974 -	392 512	375 500	0.9914	-	-
Tihange*	PWR	1975 -	122 594	117 476	0.9897	-	-
Dodewa*	BWR	1968 - 1997	5 926	5 710	0.9843	-	-
Brunsbuettel	BWR	1977 -	21 085	20 003	0.9997	0.9779	0.0010
Brokdorf	PWR	1986 -	15 505	14 769	0.9957	0.7073	0.0009
Kruemmel	BWR	1984 -	35 882	33 745	1.0085	0.2662	0.0012
Stade	PWR	1975-2003	43 456	40 771	1.0109	0.1174	0.0021
Unterweser	PWR	1979 -	86 010	81 341	1.0029	0.5608	0.0010
Lingen	BWR	1968 - 1977	19 372	18 400	0.9985	0.8862	0.0007
Karlsruhe	BWR	1966 - 1991	149 269	140 584	1.0070	0.0624	0.0007
Ahaus	NSS	2000 -	26 427	24 866	1.0080	0.3701	0.0009
Juelich	NSS	2000 -	75 735	71 688	1.0020	0.7076	0.0008
Eilweiler	UM	1969 -	31 361	29 450	1.0100	0.2225	0.0013
Menzenschwand	UM	1969 -	132 037	124 574	1.0052	0.1892	0.0012
Gorleben	NSS	2000 -	1 753	1 573	1.0570	0.1108	0.0010
Hanau/Kahl	NFE	1969 -	54 772	51 343	1.0118	0.0577	0.0021
German states and Switzerland < 35 km from NF			2 532 471	2 393 556	1.0035	** 0.0008	
German states and Switzerland > 35 km from NF			7 948 690	7 538 729	1.0000	1.0000	

### 3.3 German municipalities 1957 to 2010

Kusmierz et al. [2010] compiled official gender specific annual live births statistics for all municipalities in Germany. To calculate the distances of the municipalities from nuclear facilities, we determined uniform coordinates for the geographic positions of those municipalities including the geographic positions of 28 pertinent nuclear facilities including all major nuclear power plants in Germany and Switzerland. We now use the same data background for the evaluation of the sex odds in the vicinity of chemical sites in Germany [see Voigt et al., in this volume].

### 3.4 Statistical Methods

To assess time trends in the occurrence of boys among all live births, and to investigate whether there have been significant changes in the trend functions in

1957 or later, 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 1996 on is defined as  $d_{1996}(t) = 0$  for  $t < 1996$  and  $d_{1996}(t) = 1$  for  $t \geq 1996$ . The simple and parsimonious logistic model for a trend and a jump in 1996 has the following form (LB = live births):

Boys<sub>t</sub> ~ Binomial(LB<sub>t</sub>,  $\pi_t$ )

log odds ( $\pi_t$ ) = intercept +  $\alpha * t$  +  $\beta * d_{1996}(t)$

To allow for changing sex odds trend slopes (broken sticks) after Chernobyl, we used dummy coding of time windows and interactions of those time windows with time. The data in this study were processed with Microsoft Excel 2003. For statistical analyses, we used R 2.11.1, MATHEMATICA 5.0, and mostly SAS 9.1 (SAS Institute Inc: SAS/STAT User's Guide, Version 9.1. Cary NC: SAS Institute Inc; 2003).

### 3.5 Modelling Techniques: Simple jump function and Rayleigh function

For the further evaluation of the sex odds trends in the vicinity of nuclear facilities we used two different modeling techniques: a simple jump function, which expresses the jumps in the data, and a Rayleigh function, which shows a smooth curve, impartial and without a prefixed distance category (s. Figure 1 for operational definitions).

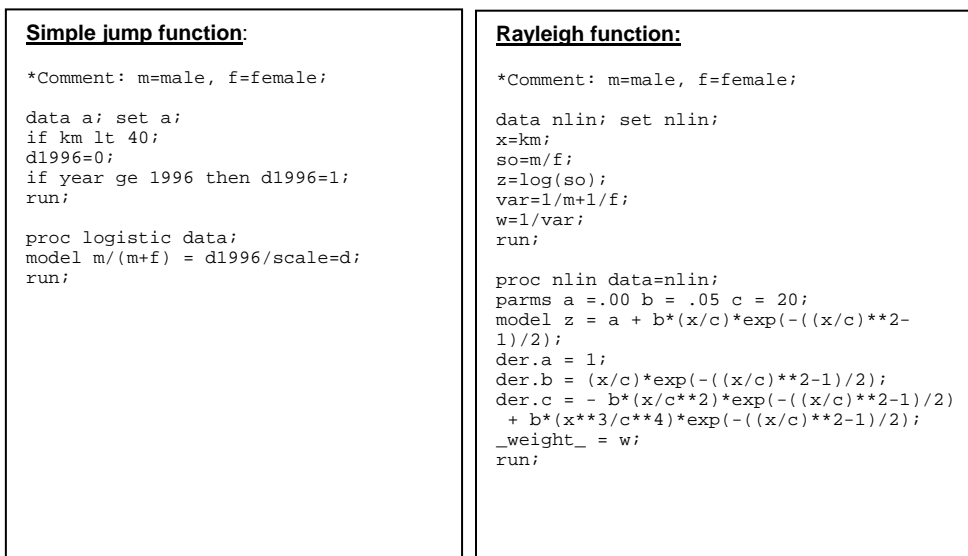


Figure 1. SAS code for simple jump function (lhs) / Rayleigh functions (rhs)

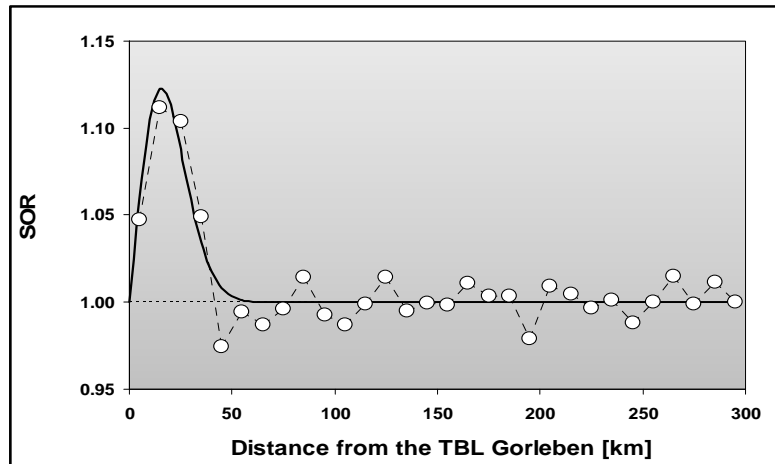
## 4 RESULTS OF THE LOGISTIC REGRESSION APPROACH TO SEX ODDS NEAR NUCLEAR FACILITIES

A study performed by the authors [Kusmierz et al., 2010] and [Scherb and Voigt, 2011] revealed an increase in sex odds in the vicinity of running nuclear facilities, especially around the nuclear storage site TBL Gorleben (Transportbehälterlager: nuclear waste shipping casks storage) in Lower Saxony, Germany. In Germany a

continuous discussion about the nuclear waste shipping casks storage in Gorleben increased our interest in taking a closer look at this location. The data analysis was performed in two ways: first we applied the above outlined Rayleigh function (distance law) and in a second step the trend and jump function (trend analysis).

#### 4.1 Rayleigh function applied on the data of the TBL Gorleben

The corresponding sex odds ratio (SOR) distance law around the TBL Gorleben is shown in Figure 2.

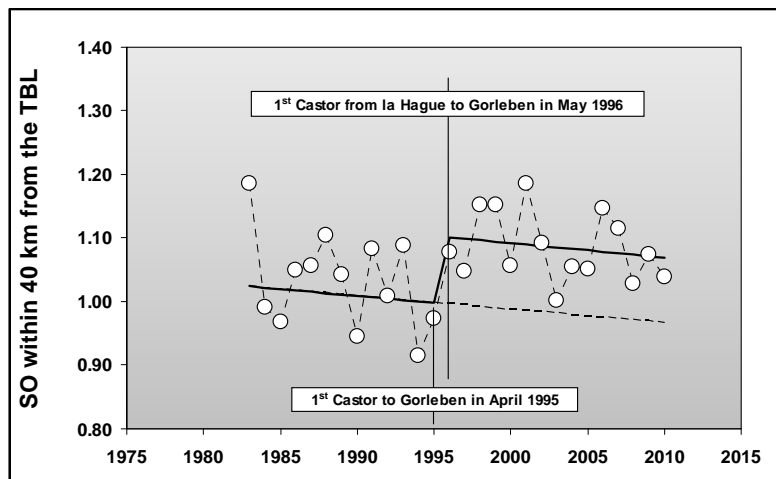


**Figure 2.** Rayleigh function for the evaluation of distance trends from the TBL Gorleben [to be published in Scherb and Voigt, 2012]

In Figure 2, the distance law of the sex odds ratio (SOR) is shown, i.e., sex odds ratios in 10 km rings: sex odds after 1995 divided by sex odds before the first Castor went to Gorleben in April 1995. The F-test p-value is 0.0091, which means that the Rayleigh curve significantly improves the fit to the data.

#### 4.2 Jump function applied on the data of the TBL Gorleben

In Figure 3 we model the trend and jump function for the time period 1983 till 2010. The significant p-value for the jump is 0.0042.



**Figure 3.** Jump function for the evaluation of the sex odds trend within 40 km distance from the TBL Gorleben from 1983 to 2010

#### 4.3 Discussion of results concerning the shift of sex odds around Gorleben

As mentioned above, people in the municipalities around the TBL Gorleben have been and still are extremely worried about the human and environmental health impacts this nuclear storage site might imply. This enduring concern together with our results triggered an official study by the "Niedersächsisches Landesgesundheitsamt" [Hoopmann, 2011], which, on the one hand, confirmed our finding for Lower Saxony and, on the other hand, corroborated it by fresh data from the remaining municipalities within 35 km belonging to Mecklenburg-West Pomerania, Saxony-Anhalt, and Brandenburg. The elevated sex odds around Gorleben might be due to an increased scattered neutron dose that tripled as far as 2 km away from the TBL in the village of Gorleben after the TBL went in operation in April 1995 [GNS, 2007]. It is possible that the biologically or genetically effective neutron dose is severely underestimated by established radiation protection standards [Heimers, 2000, 2006]. Also, the significant Rayleigh curve in Figure 2 might be the epidemiological reflection of a far reaching direct or indirect scattered neutron "skyshine" effect [Lagutina et al., 1989], although no physical model for such far reaching direct neutron radiation seems to exist as yet.

### 5 CONCLUSIONS AND OUTLOOK

Human sex ratio at birth, conventionally expressed by the number of male live births per female live births, is about 1.05-1.06 and remarkably constant [Ein-Mor et al, 2011]. Some environmental hazards can alter the sex ratio at birth. The authors have been studying the effects of ionizing radiation for several years now. Scherb and Voigt [2007] investigated the trends in the sex odds before and after the Chernobyl accident. Gender-specific annual birth statistics were obtained from the Czech Republic, Denmark, Finland, Germany, Hungary, Norway, Poland, and Sweden between 1982 and 1992. For parts of Germany, annual birth statistics and fallout measurements after Chernobyl are available at the district level. The findings suggest a possible long-term chronic influence of the Chernobyl Nuclear Power Plant accident on the human sex odds at birth in several European countries. Further studies were expended to investigate the effect of running nuclear facilities [Kusmierz et al, 2010], [Scherb and Voigt, 2011]. In these studies, influences of ionizing radiation on the sex odds at birth were also noticed. It has to be stressed that we evaluate large data sets in the range of tens to hundreds of million births. Only recently, the scope of interest has been amplified to the effects of chemical sites on the human sex odds at birth [see Voigt et al., in this volume]. Both, increases and decreases in the human sex odds provide a strong indication that there is an impact of man-made facilities on the human genome. Further background concerning this issue is given by Sperling et al. [2012]. We are of the strong opinion that we have to extend our work to other data sets. We are planning to evaluate the complete German data set including the new German states. The difficulties in the data collection and geo-informatics aspects are outlined by Kusmierz et al. [this issue]. Furthermore, we will evaluate the human sex odds at birth around the nuclear facilities in France.

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