Childhood Cancer in the Vicinity of German Nuclear Power Plants

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An epidemiologic study published in 1997 reported no significant rise in childhood cancer rates around West German nuclear power plants. The conclusions of this study were extensively used by politicians and lobbyists as proof of no increased cancer risk around nuclear power plants. A reanalysis of the data, however, reveals a statistically significant increase of childhood cancers (all malignancies) when the evaluation is restricted to commercial power reactors, the vicinities closest to the plants, and children of the youngest age group (0-4 years). The findings remain unchanged when the Krümmel reactor, with its known leukemia cluster, is excluded from the analysis. [M&GS 1999;6:18-23]

In November 1997, the German Minister for the Environment and Nuclear Safety announced to the media the results of a new investigation dealing with the incidence of leukemia and other malignant diseases in children living near nuclear power plants (NPPs) [1]. According to the Minister, the investigation had unequivocally proven that no risk exists. The study's conclusions were quoted extensively in the media and were readily exploited by lobbyists and supporters of nuclear power in the ongoing debate about health risks of NPPs in Germany.

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The new study was essentially an update of an earlier study [2, 3] carried out by the Institute of Medical Statistics and Documentation (IMSD) in Mainz, Germany. The first study, covering the years 1980 to 1990, had found a highly significant increase in early infant leukemias within 5 km of all nuclear installations. The authors of the extended study (1980-1995) concluded that these risks were no longer significant. Furthermore, they claimed that no further research was necessary, since the new study had been based on more than 2,500 cases, and that the hitherto controversial issue was finally resolved.

In several previous studies in Germany and in other countries, however, increased leukemia rates near nuclear installations had been observed. Increased leukemia rates were reported for children living in the town of Seascale [4,5], near nuclear weapon factories in Great Britain [6], in the vicinity of the nuclear installation of Dounreay, Scotland [7], near the French nuclear reprocessing plant of La Hague [8], and for several locations in Germany [9]. Recent results from Japan, though based only on mortality, seem to confirm the general association [10,11]. A comprehensive study around nuclear power plants in England [12,13], again revealed significant increases in cancer mortality rates.

Conflicting Conclusions

The results of the first IMSD report [2,3] were generally in line with the observations referenced above. The negative findings in the updated report prompted a re-evaluation of the evidence and of the IMSD conclusions. To date, the new study has not been published in the scientific literature. The re-evaluation presented here is therefore based on a Technical Report provided by the IMSD [1].

In 1990-91, an unprecedented time-space cluster of childhood leukemia cases was observed in the immediate vicinity of the Krümmel nuclear boiling water reactor (BWR) [14,15]. Clusters in the vicinities of two other German BWRs (Lingen and Würgassen) had been reported earlier [16-18] and were reviewed [9]. These observations raised some concern about possible systematic differences in the emissions of the two reactor types. Unlike pressurized water reactors (PWRs), which have a secondary cooling circuit separating the radioactive primary water from the turbines, BWRs pass the steam in the primary circuit directly through the generating turbine. Due to this technical difference, BWRs are generally considered to release more radiation to the environment than comparable PWRs.

Based on data from the IMSD, the authors investigated whether childhood cancer rates (all malignancies) and in particular, childhood leukemia rates near the 15 sites of German commercial nuclear power reactors show increases compared to the defined control areas [1]. The 15 NPP sites were further subdivided into 7 BWR sites and 8 PWR sites. All sites with both types of reactors were considered BWR sites. To see whether a possible increased risk around NPPs is solely due to the Krümmel site with its known cancer cluster, the analyses were repeated with the Krümmel NPP excluded.

Material and Methods

Since 1980 all incident childhood malignancies are registered in the National Childhood Cancer Registry at the Institute of Medical Statistics and Documentation (IMSD) in Mainz, Germany. The data are used in epidemiologic research projects conducted by the IMSD. They are, however, not released to other scientists. The authors of the IMSD studies on childhood malignancies in the vicinity of German nuclear power plants were contacted, but access to the original data was not granted. The present analyses are therefore based on tables of data published in the appendices of the IMSD Technical Report [1]. Upon special request, site specific data for children below age 5 were also obtained from the IMSD in an aggregate form (i.e. all nuclear facilities, all 15 NPP sites, and all BWR sites, respectively).

In the IMSD report, the study areas around NPPs were compared with matched control areas with similar population densities and social structures. Standardized incidence rates (SIRs) were calculated for the study areas and the control areas. SIRs were defined as the number of observed cancer cases divided by the number of expected cases. Expected cases were calculated based on the population size in each age stratum and the average age-group-specific childhood cancer incidence rate in Germany. The relative risk is defined as the ratio of the SIR in the study group, divided by the SIR in the control group.

In all calculations, the hypothesis H1—that there is an observed increase in childhood cancer rates around the sites of nuclear power plants compared to control areas—is tested against hypothesis H0—that the number of observed cases is less than or equal to the number of expected cases.

> A significant (22%) increase of childhood cancers was found around the 15 commercial power reactors.

The method described in the earlier IMSD study [2,3] was used to test for statistical significance. A statistical test provides a "p-value," which is the probability that the test result occurs by chance. According to a generally accepted convention, a p-value less than 0.05 is considered statistically significant and, hence, sufficiently unlikely to be due to chance. The more recent IMSD report provides two-sided p-values. These p-values correspond to the question whether the cancer rates near NPPs differ from the expected rates, irrespective of the direction of the difference. No mechanism has so far been discovered through which the presence of a nuclear power plant could *reduce* childhood leukemia risk. The authors believe, therefore, that the hypothesis under study is whether childhood cancers are significantly increased around NPPs; that this hypothesis is a genuine one-sided question; and that, consequently, a one-sided p-value should be provided. This approach is consistent with the earlier IMSD study, which had also calculated one-sided p-values [1].

In addition to sites of commercial nuclear power plants, the authors of this earlier study included sites of two nuclear research facilities (Karlsruhe and Jülich), one small research reactor (Kahl, capacity 16 MW) that was decommissioned in 1985, one prototype high temperature reactor (Hamm-

Table 1: West German nuclear facilities included in IMSD-study

Site	reactors (abbrev.)	Type[1]	Capacity MW(el)	1st criticality	Year decom-missioned
1. Kahl	VAK	BWR	16	1960	1985
2. Karlsruhe	MZFR	D_2O	58	1965	1984
	KNKII	NaR	20	1977	1991
3. Gundrem-mingen	KRB I	BWR	252	1966	1977
	KRB IIB	BWR	1,344	1984	
	KRB IIC	BWR	1,344	1984	
4. Jülich	AVR	HTR	15	1966	1988
5. Lingen	KWL	BWR	268	1968	1985
	KKE	PWR	1,363	1988	
6. Obrigheim	KWO	PWR	357	1968	
7. Würgassen	KWW	BWR	670	1971	1994
8. Stade	KKS	PWR	672	1972	
9. Isar	KKN	BWR	100	1972	1975
	KKI 1	BWR	907	1977	
	KKI 2	PWR	1,420	1988	
10. Biblis	KWB-A	PWR	1,225	1974	
	KWB-B	PWR	1,300	1976	
11. Neckar-westheim	GKN I	PWR	840	1976	
	GKN II	PWR	1,365	1988	
12. Brunsbuettel	KKB	BWR	806	1976	
13. Unterweser	KKU	PWR	1,320	1978	
14. Philippsburg	KKP I	PWR	912	1979	
	KKP II	PWR	1,402	1984	
15. Grafenrheinfeld	KKG	PWR	1,345	1981	
16. Hamm-Ûntrop	THTR-300	HTR	307	1983	1988
17. Krümmel	KKK	BWR	1,316	1983	
18. Grohnde	KKG	PWR	1,430	1984	
19. Mülheim-Kärlich	KMK	PWR	1,302	1986	1987
20. Brokdorf	KBR	PWR	1,395	1986	

1. PWR=pressurized water reactor; BWR=boiling water reactor; HTR=high temperature reactor, D_2O = reactor using heavy water (D_2O) as a coolant/moderator, NaR = fast breeder reactor using sodium as a coolant.

Table 2: Childhood cancers (0-14 years, 0-5 km region, all malignancies)

	O(NPP)	E(NPP)	O(C)	E(C)	RR	p-value[1]
all facilities	135.0	124.4	1,092.0	1,046.5	1.04	0.345
15 NPP sites	93.0	74.5	578.0	566.8	1.22	**0.047**
BWRs	49.0	35.5	307.0	311.3	1.40	**0.021**
PWRs	44.0	39.4	271.0	255.5	1.05	0.403
other facilities	42.0	49.4	514.0	479.7	0.79	0.939
NPPs-Krümmel	83.0	67.4	551.0	536.1	1.20	0.073
BWRs-Krümmel	39.0	28.0	280.0	280.6	1.40	**0.035**

O = observed cases; E = expected cases; NPP = study area around nuclear power plants; C = control area; RR = relative risk
1. One-sided p-value
2. P-values in bold are statistically significant

Üntrop, 307 MW) that operated for a total of about 400 days, and a commercial reactor (Mülheim-Kärlich) that operated for several months (Table 1).

Since the radioactive inventory of research reactors is only 0.01-0.001 times that of typical commercial reactors, the authors were reluctant to evaluate both groups together. Power reactors with a very short time period of operation were also excluded, since their contribution to the overall population exposure was small compared to the remaining reactors that were operated on average for more than 15 years. Hence, this analysis was restricted to the 15 sites of commercial reactors.

In all analyses, IMSD's matched 15-km control regions were retained for each of the respective nuclear sites. While the study areas were subdivided into concentric regions of 0-5, 5-10, and 10-15 km radius, these were always compared with the complete 15 km control regions.

Results

Both IMSD studies included all 20 sites of nuclear reactors in Germany. Sites were chosen as the unit of observation rather than nuclear reactors since, at a few of the sites, multiple nuclear reactors are, or have been, in operation for various periods of time between 1980 and 1995. All nuclear installations under study are listed in Table 1. At some of the sites, both pressurized water reactors and boiling water reactors were operated. These sites are categorized here as BWR sites.

This paper focuses on the 0-5 km regions of the 15 commercial NPP sites. After evaluating the risks for all children below age 15, the authors further restrict the analyses to early childhood cancers (i.e. children less than 5 years of age). The results of these calculations are presented in tables 2-5.

All childhood malignancies (0-14 years): In agreement with [1], no excess risk is yielded when all 20 nuclear facilities are taken together (RR=1.04; p=0.345). A significant (22%) increase of childhood cancers (all malignancies), however, was found around the 15 commercial power reactors (p=0.047; Table 2). There are 93 observed vs. 74.9 expected cases in the study area and 578 vs. 566.8 in the control area. The increased overall risk around NPPs is essentially attributable to the BWR sites where the RR is 1.40 (p=0.021), while the RR is only 1.05 around the PWR sites. The increased RR around the BWR sites remains statistically significant even when the Krümmel BWR is excluded from the analysis (RR=1.40, p=0.035; Table 2).

Acute childhood leukemias: The increase in acute childhood leukemias is 34% around the commercial NPP sites. Due to small numbers, this increase is not statistically significant (p=0.073; Table 3). The incidence rate around all 20 nuclear facilities is considerably smaller (RR=1.12; p=0.258).

Without the Krümmel NPP, the RR around all commercial reactors is 1.13. All BWRs yield an RR of 1.45 (p=0.098). After exclusion of the Krümmel BWR, this RR becomes 1.0. Hence in this analysis the statistically non-significant (45%) increase of acute leukemia risk near BWRs is entirely attributable to the BWR Krümmel.

Early infant malignancies (0-4 years): Around the 15 commercial reactor sites, a statistically significant (53%) increase of cancer rates (all malignancies) was observed; the corresponding p-value is p=0.0034 (Table 4). The increase is more pronounced around BWR sites (RR=1.70, p=0.008) compared to PWR sites (RR=1.40, p=0.085). Exclusion of the Krümmel BWR does not substantially change the RR (RR=1.53, p=0.006).

Around the other nuclear facilities, the risk is significantly reduced compared to the control areas (RR=0.48). This explains the non-significant overall risk for early infant malignancies around all 20 nuclear facilities provided in the IMSD report (RR=1.10, p=0.258).

Early infant leukemias (0-4 years): In this age group the increase of acute leukemia incidence (RR=1.76, p=0.012) around all commercial sites is somewhat more pronounced than the increase for all malignancies (Table 5). There is no substantial difference in risk near BWRs (RR=1.86, p=0.038) and PWRs (RR=1.71, p=0.087). Even when evaluating all 20 nuclear facilities, the increase is statistically significant (RR=1.49, p=0.029). Excluding the Krümmel BWR, the relative risk around commercial reactors is 1.49 (p=0.077), and 1.33 around BWRs (p=0.276).

All childhood malignancies; dependent on distance: Table 6 gives the numbers of all malignancies in children below age 15 in the three distance rings from the 15 NPP sites. As already pointed out, the increase is 22% in the 5 km zone, while no increase is found in the two outer distance rings (5-10 km: RR=1.01; 10-15 km: RR=0.92). This analysis reveals a significant direct relationship between RR and the inverse distance from the site (p=0.028, one-sided test). The incidence rate in the inner 5 km zone was also compared with the rates in the combined two outer zones (5-15 km); the combined two inner zones (0-10 km) were then compared with the outer zone (10-15 km). Using the binomial test, the incidence rates in the inner zones were found to be significantly higher in both cases than in the outer zones (p=0.017 and p=0.034 respectively, Table 6).

Table 3: Childhood leukemias (0-14 years, 0-5 km region)

	O(NPP)	E(NPP)	O(C)	E(C)	RR	p-value[1]
all facilities	48	42.4	362	357.1	1.12	0.258
15 NPP sites	35	25.6	198	193.1	1.34	0.073
BWRs	18	12.1	109	105.7	1.45	0.098
PWRs	17	13.5	89	87.4	1.24	0.248
other facilities	13	16.9	164	164.0	0.77	0.850
NPPs-Krümmel	27	23.0	190	182.7	1.13	0.305
BWRs-Krümmel	10	9.5	101	95.3	1.00	0.552

O = observed cases; E = expected cases; NPP = study area around nuclear power plants; C = control area; RR = relative risk

1. one-sided p-value

Table 4: Early childhood cancers (0-4 years, 0-5 km region, all malignancies)

	O(NPP)	E(NPP)	O(C)	E(C)	RR	p-value[1]
all facilities	67	58.8	510	490.4	1.10	0.258
15 NPP sites	55	36.2	270	272.7	1.53	**0.0034**
BWRs	30	17.1	156	151.5	1.70	0.008
PWRs	25	19.0	114	121.3	1.40	0.085
other facilities	12	22.6	240	217.7	0.48	0.998
NPPs-Krümmel	49	32	258	257	1.53	**0.006**
BWRs-Krümmel	24	13	144	136	1.74	**0.011**

O = observed cases; E = expected cases; NPP = study area around nuclear power plants; C = control area; RR = relative risk

Bold type indicates statistical significance

1. One-sided p-value

Discussion

In this reanalysis evidence was observed of significant increases of early childhood cancer incidence and, particularly, leukemia rates near German commercial nuclear power reactors in the time period 1980-1995. The overall increase cannot be accounted for by the known leukemia cluster at the Krümmel BWR since the RR remains high even after exclusion of the Krümmel site. These findings contradict the conclusion of the official IMSD report [1].

Since a beneficial effect of ionizing radiation on childhood cancer is considered impossible, a one-sided significance test was applied throughout these analyses. Nevertheless, the results for early chidhood cancers (p=0.007) as well as for acute leukemias (p=0.024) would remain statistically significant, even were the two-sided test used. For all malignancies in children below age 15, the two-sided test does not achieve statistical significance around all 15 commercial nuclear reactor sites. For BWR sites alone, however, a significant increase is observed.

The numbers of cases are small: for children below age 15 there are 19 excess cancers in the 16-year study period. The same excess is obtained with children below age 5.

It should be understood that due to the ecologic nature of this study, increased relative risks merely represent associations and

Table 5: Early childhood leukemias (0-4 years, 0-5 km region)

	O (NPP)	E (NPP)	O(C)	E(C)	RR	p-value[1]
all facilities	31	21.4	174	179.4	1.49	0.029
15 NPP sites	24	13.3	103	100.0	1.76	0.012
BWRs	13	6.3	62	55.4	1.86	0.038
PWRs	11	7.0	41	44.6	1.71	0.087
other facilities	7	8.1	71	79.4	0.96	0.594
NPPs-Krümmel	19	12	101	95.3	1.49	0.077
BWRs-Krümmel	8	5	60	50	1.33	0.276

O = observed cases; E = expected cases; NPP = study area around nuclear power plants; C = control area; RR = relative risk
1. one-sided p-value

Table 6: Childhood cancer rates around commercial power reactors by distance (0-14 years, all malignancies)

km	O (NPP)	E (NPP)	O(C)	E(C)	RR	p-value[1]
0-5	93	74.5	578	566.8	1.22	0.042
5-10	292	283	578	566.8	1.01	0.454
10-15	411	437	578	566.8	0.92	0.896
0-5 vs. 5-15	93	74.5	703	719.4	1.28	0.017
0-10 vs. 10-15	385	357.8	411	436.1	1.14	0.034

O = observed cases; E = expected cases; NPP = study area around nuclear power plants; C = control area; RR = relative risk
1. one-sided p-value

must not be interpreted as a proof of causality. Nevertheless, the results are consistent with an actual influence by German nuclear power plants on childhood cancers:

ß The IMSD findings are generally consistent with published results from Germany and other countries.

ß The increased risks are confined to the immediate vicinity of the plants. This would be expected if NPPs were in fact point sources of any actual risk factor (e.g. radioactive emissions).

ß Relative risks are higher around BWRs, which are known to release higher quantities of radionuclides than PWRs [19].

ß Relative risks are higher for acute leukemia for which a radiogenic etiology is firmly established

ß Relative risks are higher for younger children. This again would be expected since it is known that radiosensitivity is higher in early childhood and even higher prenatally [20-22].

The observed 53% increase of early infant cancer rates in the vicinity of NPPs is much greater than expected based on the estimated radioactive releases by German NPPs. Extrapolation of radiogenic risk from higher doses to the very low dose range under the prevailing assumption of a linear dose-response relation would not result in any detectable excess risk. Radiobiological knowledge about the effects of very low cumulative doses and dose rates (dose per unit time) of ionizing radiation is inconclusive, however, and data is virtually lacking. Instead, there is an ongoing controversy among experts about the quantitative effect of very small doses, especially with respect to incorporated radionuclides. Some experts claim that there might be a highly increased sensitivity of the human organism at very low doses and that the extrapolation from high doses underestimates the low dose effect of radiation [23].

To clarify whether or not low levels of ionizing radiation pose a health risk to the general population, analytical instead of descriptive epidemiology is required. Two recent analytical studies seem to support an actual health risk. In a case control study, Morris and Knorr [24] observed a statistically significant positive association between risk of leukemia (all forms except chronic lymphatic leukemia [CLL]) and individual accumulated exposure to airborne emissions from the Pilgrim BWR (Massachusetts, USA). Another case control study observed an increased leukemia risk around the La Hague reprocessing plant (LaHague, France) [25]. There, the excess leukemia risk was found to be associated with use of local beaches and local shellfish consumption.

Conclusion

The 1997 IMSD report [1] presently provides the most detailed analysis of childhood cancers around nuclear power plants in Germany. Its negative conclusion, however, need to be questioned.

The observed increase in the cancer rate for the most vulnerable (youngest) subgroup near commercial nuclear reactors deserves particular attention. The issue of adverse health effects in the vicinity of NPPs is far from resolved and definitely requires further study.

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The observed 53% increase of early infant cancer rates in the vicinity of NPPs is much greater than expected based on the estimated radioactive releases by German NPPs.

Acknowledgments

The authors wish to thank Professor J. Michaelis at the ISDM for providing the data, Hagen Scherb for his help with the statistical treatment, and John Otranto for help with the translation and valuable comments.