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Review Article

Is There Evidence of Adverse Health Effects Near US Nuclear Installations? Infant Mortality in Coastal Communities near The Diablo Canyon Nuclear Power Station in California, 1989-2012

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Abstract

Following the recent cancellation of the Nuclear Regulatory Commission proposed study of cancer near nuclear sites in the USA, an attempt is made to investigate the effects of local exposures to radioactive release by employing infant mortality as an indicator of genetic effects of radioactive releases on birth outcomes. Nuclear plants which are built on the coast and which release radioactivity to the environment contaminate the coastal strip. A comparison of official annual infant mortality data for ZIP coded areas near Diablo Canyon nuclear plant adjacent to the sea with those inland for the 25 years from 1989 to 2012 showed a remarkable and statistically significant 28% overall increase in infant mortality rates in the coastal strip group relative to the inland control group. Furthermore, over the period of the study, infant mortality rates for the whole of California fell, as did rates in the local inland control group; however, following an initial fall, the rates in the coastal region near the nuclear plant continuously increased. The effects cannot be explained by demographic changes in the Hispanic/ white population in the study areas. The increases over the period correlate significantly with cumulative releases of Tritium from the nuclear plant to the sea, p=0.027. Whilst these data do not prove causation they suggest that an investigation of cancer rates near this and other nuclear plants should be carried out.

Keywords: Nuclear; Infant Mortality; Radiation; Genetic Damage; Diablo Canyon; Tritium

Introduction

The effects on local populations of licenced releases of radioactivity from nuclear plants remain a matter of concern. Originally, focus was on childhood leukemia rates, since this was believed to be the best indicator of radiation effects, and indeed a number of studies appeared to show an excess risk of leukemia in children living within 5km of nuclear sites. There are statistical power problems with studies of child leukemia since the background rates are very low, and it was pointed out that studies of adult cancers, particularly breast cancer, which has an accepted radiogenic connection, might be more productive of information on this important public health issue [1].The question was part of the deliberations of the UK Committee Examining Radiation Risk from Internal Emitters CERRIE, however although a number of conclusions about how such studies should be approached were included in the final reports [2,3] the study of breast cancer in population wards near the Bradwell nuclear plant in Essex was cancelled and the committee was wound up. The Bradwell study itself was completed and published in 2012 [4]. It showed a significant excess 2-fold mortality risk from breast cancer in coastal wards adjacent to the nuclear plant where radioactive discharges were measured in coastal sediment and in samples from coastal locations on land. This was followed by the publication of a study of breast cancer and infant mortality in coastal populations near a different nuclear site, the Hinkley Point nuclear power plant in Somerset UK where there was again a doubling of breast cancer mortality risk found in the downwind and coastal population. But the Hinkley Point study also looked at infant mortality, on the well accepted basis that radioactive exposures cause their cancer effects through causing genetic (or genomic) damage, and that such damage would also perhaps result in effects on birth outcomes [5]. Other studies in the

USA have drawn attention to the effects of nuclear site releases upon infant mortality [6,7].

In the USA, the question of the possible adverse health effects of licenced releases from nuclear plants has been a matter of debate since the 1990s and proposals from a pilot study of cancer near 7 nuclear plants in the USA were discussed by the US National Academy of Sciences who proposed a scheme, "Analysis of cancer risks in populations near nuclear facilities" [8] to be carried out by the US Nuclear Regulatory Commission (NRC). The NRC cancelled the study in September 2015 [9].

Independent analysis of cancer risks near point sources is prevented by the refusal to release cancer data by small area in the USA. The releases of radioactivity under licence results in the accumulation of radioactive contamination in local areas and the radioactive exposure of populations in such areas. The conventional epidemiological approach to such studies has been to examine child leukemia rates in regions defined by concentric rings around the plant, modelled as a point source. Using such methods, German researchers showed a significant excess risk of child leukemia within a 5km radius of all plants in Germany over a significant period [10]. However, it was pointed out by the UK Committee Examining Radiation Risk from Internal Emitters (CERRIE) that the contamination patterns from nuclear plants will not in general be radially symmetrical but will rather follow water courses and wind direction defined regions. For plant built near the sea, the contamination is either directly or indirectly (through land drainage) released to the sea, and will then contaminate coastal areas close to the plant. Here, the phenomenon of sea-to-land transfer will result in inhalation exposure and exposure through routes associated with higher levels of coastal contamination which have been shown to exist in the Irish Sea and Baltic Sea areas of the world [2,3]. In a very large study discussed by the CERRIE committee and also described elsewhere [11] it was found that communities living within a few kilometres of the radioactive contaminated coast of the Irish Sea in Wales suffered a significant excess risk of cancer. This defined a sea-coast effect in populations living near nuclear plants. Two other studies of breast cancer mortality near the nuclear sites at Bradwell [4] and Hinkley Point [5] have been mentioned confirmed such an effect. Thus it might be predicted that such a coastal effect would exist near any nuclear plant sited on the coast.

The Diablo Canyon nuclear power station in California is such a site. The station began operation in 1986 and released significant quantities or radioactive material from then to the present day. All of this will have either directly or indirectly appeared in the sea and will have contaminated the coastal regions to the north and south of the plant. Infant mortality and birth data is published by the State of California by year for Zip coded small areas. The Zip coded regions near the Diablo Canyon plant have been grouped according to their location as coastal and inland and the rates of infant mortality investigated from 1989 when the data was first published to the most recent year of publication, 2012. That gives 24 years of data. The hypothesis to be investigated is that the cumulative contamination of the coast increased the rate of infant mortality in the coastal group of Zip codes relative to the inland group over the period of the study.

Method

Data for births and for infant deaths by year and by Zip code was obtained from the website publications of the State of California [12]. There were three areas examined and compared. These were a coastal area A, an inland area B in San Luis Obispo County, and the whole of California C. Details of the birth populations are given in Table 1 and shown in the map in Figure 1.

Figure 1. Zip code areas employed in this study in San Luis Obispo County California. Red circle defines a 15 mile radius from the nuclear plant (from Mangano 2014 [13], see Discussion).

The 24 year period was divided into four six year periods and births and infant deaths in each Zip code group were summed to obtain crude infant mortality rates per 1000 births. The rates were then compared between the two groups A and B and with the whole of California. Relative Risk for infant mortality was then obtained by standardising the rate in the exposed group A against the control group B and applying standard statistical methods to examine the comparison results.

Zip Code	Name	Births1 89-94	Births2 95-2000	Births3 2001-2006	Births4 2007-2012
Coastal Group A					
93402	Los Osos	1015	755	744	803
93424	Avila Beach	35	29	33	38
93433	Grover Beach	1358	1238	1076	1062
93434	Guadalupe	936	769	930	883
93442	Morro Bay	692	533	569	542
93445	Oceano	866	822	741	695
93449	Pismo Beach	459	424	318	305
All A		5361	4570	4411	4328
Inland Group B					
93401	San Luis Obispo	1984	1515	1395	1368
93405	San Luis Obispo	442	672	652	700
93420	Arroyo Grande	1723	1534	1470	1504
93422	Atascadero	2287	1790	2001	2126
93432	Creston	89	65	81	93
93444	Nipomo	1143	1157	1283	1463
93465	Templeton	474	456	452	512
All B		8142	7189	7334	7766
California					
		3531154	3177104	3252985	3160268

Table 1. The coastal and inland study group births near the Diablo Canyon nuclear plant in California by 6-year aggregated periods 1,2,3 and 4.

Results

The rates of infant mortality fell continuously in California over the whole 24 years of the study. In the control group B, the rates fell but then stabilised. In the exposed coastal group A, following an initial fall, the rates continuously rose. This is shown in Figure 2 and Table 2.

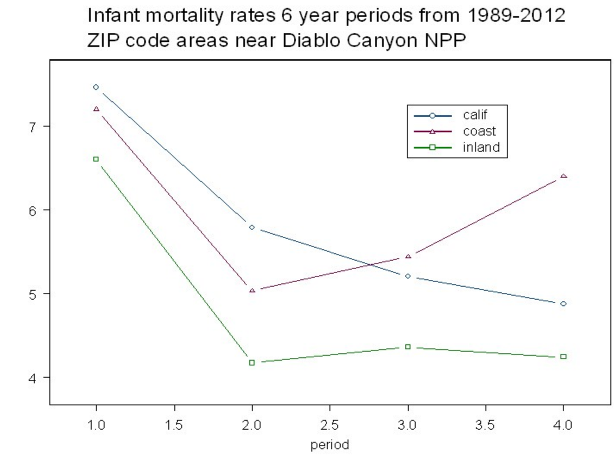

Figure 2. Infant mortality rate by four 6-year periods in three groups: Coastal Exposed Group A, Inland Unexposed Group B and All California; 1989-2012; rate per 1000 live births.

Period	Exposed A	Unexposed B	California
1. 1989-1994	7.2	6.6	7.46
2. 1995-2000	5.03	4.17	5.79
3. 2001-2006	5.44	4.36	5.2
4. 2007-2012	6.0	4.24	4.87

Table 2. Infant mortality rates in Coastal (A), Inland (B) Zip Code groups and California in the four 6-year periods from 1989-2012

Period	Observed	Expected[a]	Odds Ratio	Cumulative Poisson p-value[b]
(1) 1989-1994	39	35.38	1.10	0.20
(2) 1995-2000	23	19.06	1.21	0.15
(3) 2001-2006	24	19.23	1.25	0.10
(4) 2007-2012	26	18.39	1.41	0.04*
All 1989-2012	112	92	1.22	0.02*

[a]Expected based on rate in control group B; b Probability that no more than observed number of cases are seen.

* statistically significant

Table 3. Expected and Observed numbers of infant deaths in four 6-year periods from 1989 to 2012 and total in coastal Zip code group Group A based on rates found in Unexposed inland group Group B.

The risk in the exposed coastal group A relative to the risk in the inland control group B continuously increased throughout the period, as shown in Fig 3 and Table 3. Over the whole period, the increased risk in the coastal group relative to the internal control group was statistically significant RR = 1.29; p = 0.018. The increasing trend of risk in the exposed group area A relative to control area B over the whole period is shown in Figure 3

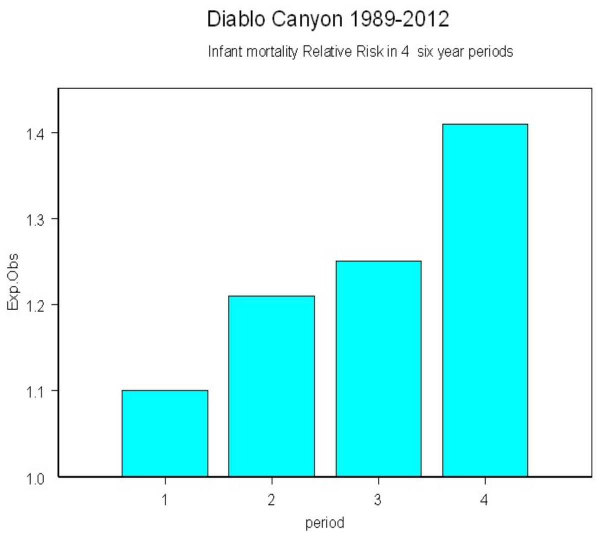

Figure 3. Expected and Observed numbers of infant deaths in four 6-year periods from 1989 to 2012 and total in coastal Zip code group Group A based on rates found in Unexposed inland group Group B.

The hypothesis to be tested is that the releases of radioactivity to the sea from the Diablo Canyon nuclear plant has caused adverse health effects in coastal populations relative to inland populations. Thus it is of interest to see if there is any correlation between the cumulative releases from the site and the excess risk of infant mortality. Releases from the Diablo Canyon site were tabulated by UNSCEAR 2000 Tables 31-34 which show both airborne and liquid releases of noble gases, particulates, Iodine-131 and Tritium by year from 1990 to 1997 [14]. It is possible to use the Tritium release as an indicator of general releases. Tritium is a form of radioactive water with a half-life of 12 years and has been associated with harmful developmental effects in invertebrates [15] and so an examination of any correlation between the cumulative releases of Tritium over the 24-year period and the relative risk of infant mortality is of interest. There have been other reports which argue that Tritium has anomalous genotoxicity [16]. The mean annual release of Tritium as a liquid (HTO) from 1990 to 1997 was about 5000GBq. Releases by year in those years not listed by UNSCEAR 2000 from 1986 when the plant began operation and 2012 were calculated by assuming the average release by year. The 6-year cumulative mid-point releases of Tritium to the sea are given in Table 4, and a plot of these data against Relative Risk is shown in Fig 4. It will be seen that considerable quantities of Tritium were released to the sea, more than 1015 Bq. The Relative Risk was significantly correlated with the Tritium releases, with a t-value of 6.12 p=0.026; R2 = 0.9423, F-Statistic 37.46, p=0.026. This is, of course, a correlation and cannot prove causal association.

Period	Cumulative Tritium released from start of operation 1986 GBq to centre of period
1. 1989-1994	274700
2. 1995-2000	603000
3. 2001-2006	903000
4. 2007-2012	1203000

Table 4. Cumulative Tritium releases to the sea from the Diablo Canyon Nuclear power station in the four 6 year periods in 1989-2012 GBq (109Bq)

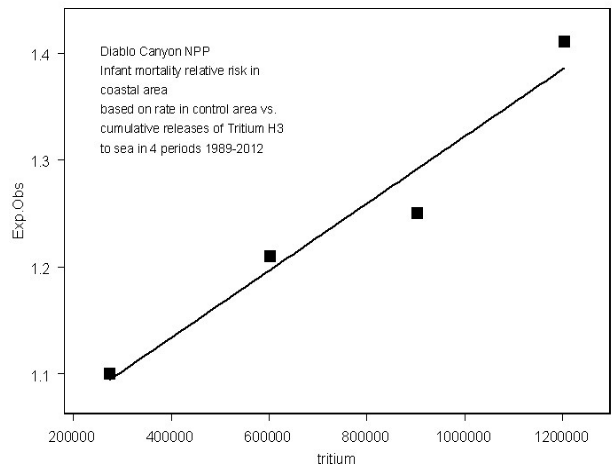

Figure 4. Correlation between Relative Risk of infant mortality in coastal (exposed) group A based on rate in inland (unexposed) group B and cumulative releases to the sea of Tritium (Tritium data GBq from UNSCEAR2000 [14]). For statistics see text.

Year	Coastal Group A	Inland Group B	California
1989	32.6	16	45.6
2000	47.5	25	60.5
2010	52	32	65

Table 5. Hispanic births as a percentage of Hispanic + White births in the study groups and in all California over the period of the study.

Discussion

It is widely accepted that cancer is a genetic disease expressed at the cellular level and that environmental carcinogens, like ionising radiation, are causally related to cancer [17]. The genetic or genomic damage caused by exposure to ionising radiation also causes germ cell and development damage which clearly leads to infant mortality. There is significant evidence that such damage can occur and very low doses of internal exposure to certain radionuclides. Evidence for low dose effects on infant mortality has been published for offspring of those exposed to atmospheric test fallout in the 1960s [18,19], near nuclear power stations [5-7], for nuclear test site veterans, for nuclear workers, Gulf War veterans exposed to Uranium weapons residues, and most recently after Chernobyl [20]. The sea-to-land transfer of radioactive pollution has been measured [21-23]. and the mechanisms have been elucidated. Thus it is scientifically plausible that the coastal regions near the Diablo Canyon Plant would become contaminated, and that this contamination would lead to exposures that would cause genetic or genomic damage and excess risk of cancer and heritable disease in coastal populations. The results of this study appear to support this.

A 2014 report by J Mangano [12] addressed this question using a radial risk approach, dividing Zip code regions by distance from the point source and examining birth outcomes. His analysis showed an effect, but his conclusions were attacked by the authorities principally on the basis that he had not adequately controlled for demographic changes in the Hispanic/ white birth rate in his study areas. The infant mortality rate in Hispanic births is apparently higher than in white births. The author of the report criticising Mangano stated (without any analysis) that if controlling for this was undertaken, there would be no effect [23]. Accordingly it is necessary to examine this issue for the present analysis.

The percentage of Hispanic to Hispanic+ White birth ratio in the three groups analysed here and given for relevant years in Table 5 below.

It is clear from Table 5 that a change in the Hispanic/White birth ratio cannot explain the findings. Indeed, from Fig 2 it is clear that the most significant reduction in infant mortality in the study period was in All California, with a fall from 7.46 to 4.87 per 1000 births. Even though the State began with a higher percentage Hispanic births and ended also with a higher percentage of Hispanic births the infant mortality rate ended lower than both study groups A and B. The proportion of Hispanic births in the inland unexposed group increased by a factor of 2 but in the coastal group it increased only by a factor of 1.6. Controlling for the Hispanic white ratio would therefore only increase the disparity, not account for it.

The nuclear plant releases radioactive noble gases, Iodine 131, particulates (mainly Uranium), fission and activation products and Tritium. The plant is sited on the seaward side of a mountain and it is felt that airborne releases would be significantly dissipated before reaching the populated areas of San Luis Obispo to the east of the mountain. Thus a radial effect is considered less likely than a coastal one. Large quantities of Tritium are released, as Tritiated water HTO. Studies of the effects of low doses of Tritium on invertebrate development have shown significant effects on chromosome aberration and other anomalies, though the regulators do not seem to have picked up on these results [15]. It is not implausible to connect these experimental results with the effects that appear here.

The analysis carried out here uses a coastal/ inland dichotomy on the basis that most of the contamination will be in the coastal strip for reasons which have been discussed. Nevertheless, there is no doubt that some contamination, particularly from airborne releases, will have affected the areas inland which are potentially downwind from the source. This was the basis of Mangano's study. Examination of Figure 2 shows that what has been used here as the inland unexposed control group does in fact show and effect which is mid-way between all California and the exposed group A. That is to say, the rates of infant mortality did not fall in the same trend in Group B as in all California, but rather flattened out. This may suggest that the effect of Diablo Canyon on health in the areas nearby goes beyond the coastal region.

Conclusion

Caution must be exercised in interpreting these results. There may be other explanations for the differences which are not apparent from a study of the crude figures. However, the remarkable increasing trend in infant mortality in the coastal exposed group relative to both the control inland group and to the whole of California does suggest that the effect of the releases to the sea from the Diablo Canyon plant may be responsible. Accordingly, and since this a question which has been routinely raised by the public, but as yet has not been properly studied, the results of this analysis suggest that further examination of this issue through a study of cancer effects in adults should be undertaken.

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