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Research Article

Cancer near Trawsfynydd Nuclear Power Station in Wales, UK: A Cross Sectional Cohort Study

Christopher Busby[1*], Mireille de Messieres[2]

[1]Environmental Research SIA, 1117 Latvian Academy of Sciences, Riga LV-1050, USA

[2]Green Audit, Castle Cottage, Sea View place, Aberystwyth SY 23 1DZ UK,

*Corresponding author: Prof. Dr Christopher Busby, Environmental Research SIA, 1117 Latvian Academy of Sciences, Riga LV-1050, USA. Tel: +371 29419511; Email: christo@greenaudit.org

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Abstract

A cross sectional cohort study was carried out of the population living downwind of and less than 3.5km from Trawsfynydd nuclear power station sited in Wales, UK. This station is cooled by, and discharges radionuclides to a lake, Llyn Trawsfynydd, which is significantly contaminated with radioactivity. Cancer numbers and populations were obtained through questionnaire and interview for the10-year period to 2005. Results showed that in the 3-years before the study was carried out, 2003-2005 and where completeness of data was most secure, there were significantly raised levels of cancer relative to England and Wales. Based on 490 males and 488 females the Standardised incidence ratios (SIR) for all ages were: All malignancy males 2.13 (obs: 22 exp: 10.5; 95%CI 1.34, 3.29; p<.002) All malignancy females 1.74 (obs 16, exp 9.2; CI 1.03, 2.92; p <0.05). Female breast 2.6 (obs 6, exp 2.3; CI 1.16, 5.79; p<0.03), Prostate 2.5 (obs5 exp 2.0; CI 1.01, 5.93; p <0.05), all leukemia 7.8 (obs 3, exp 0.38, p<0.007) all leukemia and lymphoma 6.5 (obs 4 exp 0.62, p<0.003), mesothelioma 18.0 (obs 2, exp 0.11, p<.005), pancreas 4.8 (obs 2 exp 0.42 p<.06). Cancer SIR were highest in the age group below 60 years in women where for breast cancer SIR was 4.9 (obs 5, exp 1.02; CI 2.02, 11.99; p< 0.004) There was an association with eating lake fish (RR = 2.1; p<0.04). Whilst owing to the structural problems associated with such studies caution should be exercised in quantitative interpretation, results show that they can be informative and that studies of adult cancer near nuclear facilities are likely to be more useful than studies of rare childhood cancer.

Keywords: Cancer; radiation; radioactivity; nuclear

Introduction

An association between childhood leukemia risk and proximity to nuclear sites has emerged since the discovery of a cluster near the Sellafield reprocessing site in Cumbria, UK in the 1980s [1]. Since then, childhood leukemia has become the first area of investigation of the risk of radiation-induced disease in nuclear site populations with studies which now show clearly that there is an increased risk in children 0-4 living within 5-km of nuclear sites [2-8]. Official responses [9-10] and those of some international risk agencies are based on the current radiation risk model, that of the International Commission on Radiological Protection (ICRP) and have generally been dismissive. The ICRP model itself is based on the cancer yield of the Japanese A-Bomb lifespan studies, which provide risk factors for cancer and leukemia based on acute high-level external exposure [11]. The methodology is to define a "dose" and relate this to the excess cancer risk. There are persuasive arguments that this method, based on external exposure is quite unsafe for chronic internal exposures [12, 13]. The ICRP risk model cannot explain or predict the nuclear site childhood leukemia by orders of

magnitude and so other explanations have been advanced [14] though none have been shown to be likely or even possible.

Epidemiological studies of childhood leukemia near nuclear sites suffer from the problem that it is a very rare event with background rates at about 6 per 100,000. Added to this that nuclear power stations are always built far from large centres of population for obvious reasons, the number of children who live within 5-km of the plants is small, and so the expected number of cases is such that studies are almost impossible to carry out. For this reason, large numbers of nuclear sites and long period of time are employed to see any statistical evidence of effect [7].

In addition to these problems are concerns about the epidemiological methods, which have been used. The matter was raised in the UK Committee Examining Radiation Risks from Internal Emitters where it was agreed that nuclear site point source studies were flawed by failure to choose groups most likely to be exposed, and rather just drew concentric rings around the source as if releases were equally likely to disperse in any direction. Furthermore, releases to the sea, which ended up on the coast, in estuaries or on rivers would confer extra risk to those living by the water and contaminated sediment [15]. It was agreed that studies should be based on areas where contamination was likely to be greatest, downwinders and those living near the contamination [16, 17].

There is also the problem with access to data. Although cancer and leukemia data has been officially gathered and recorded by place of residence since 1974 in the UK, such data is never made available for independent research.

The aim was to address all these issues. The approach overcomes the limiting statistical power of childhood leukemia studies by examining risk of cancer in adults living downwind of a nuclear power station situated inland in the UK, which discharges radioactivity to the environment both in aerial releases and to a lake. The design of the study overcomes the data access problem by collecting both cancer and population data together by questionnaire and interview. The choice of the study area, downwind of the nuclear plant, places the ecological group at risk downwind of the releases, and compares the cancer risk with the national UK population.

Method

The study area

Trawsfynydd nuclear power station is the only inland nuclear station to be built in the UK. The power station has two MAGNOX type CO2 cooled graphite moderated reactors and is situated on a lake, Llyn Trawsfynydd, which acts as a cooling water source and is also a sink for radioactivity released from the plant. A significant amount of radioactive material exists in the lake bed sediment [21, 22]. There are also gaseous releases from the plant, which is situated on the north shore of the lake. The power station ceased operation in 1993 but has yet to be fully decommissioned. The prevailing winds are south westerly. The study area was the area to the north and west of the plant. The question being addressed was whether there was an excess risk of cancer in the area downwind of the plant. This followed anecdotal evidence from some individuals living in Llan Ffestiniog. Researchers went to each house in the town of Llan Ffestiniog to the north east of the Trawsfynydd site, the village and farms near Gellilydan to the north of the plant, and a few outlying farms in Cwm Prysor to the south, which contributed a small number of questionnaires. A map of the area is given in Fig 1.

The protocol

The study was broadly based upon the method of the Burnham on Sea cancer questionnaire study [18] which in turn was piloted in Carlingford, County Louth, Ireland in 2000 [19]. The method was employed to examine cancer and infant mortality in Fallujah, Iraq [20]. First, this is mainly an ecological study. Both the population at risk and the numbers of cancer and leukemia/lymphoma were obtained by visiting each house in the pre-defined area and administering a questionnaire and conducting an interview. The interviews were mainly in Welsh and were carried out by Welsh speakers working for the Welsh language television Company S4C, a subsidiary of Harlech Television Wales (HTV). Local councillors who were aware of the purpose of the study backed up the interviewers. The questionnaire is attached as Appendix A.

The completed questionnaires were transferred to a spreadsheet and the population was entered by sex and 5-year age groups. The expected numbers of cancers of each major site were then generated by multiplying the numbers in each sex and 5-year age group by the appropriate 5-year rate obtained from the cancer incidence data for England and Wales published by the Office for National Statistics (Series MB1). The cancer risks for each site were calculated as Standardised Incidence Ratios (SIR) on the basis of England and Wales rates for 2002 [23]. Thus, the national incidence rate per 100,000 for each 5-year sex and age group was applied to the number of individuals in that age group in the base population to obtain the expected number of cases per year **E.** Two periods of time were examined. The first, which was for background interest, was the ten years 1996-2005. The second, which from previous studies we believe to represent the most accurate data on total cancer numbers was the three years 2003-2005. For each period the expected number of cancer cases for the type of cancer being considered was calculated from the appropriate national rate and the Standardised Incidence Ratio SIR was calculated as:

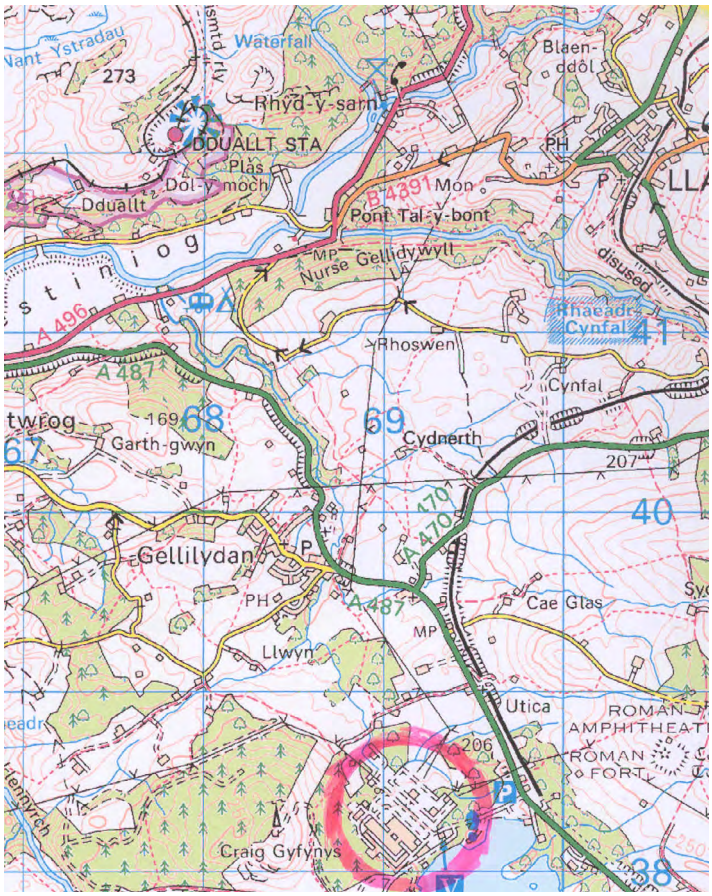
$$\mathbf{SIR = O/tE}$$

Where O is the observed number of cases, E is the expected number, and t is the time period in years. This is a standard method. The statistical significance of the result was obtained using both cumulative Poisson p-values and standard contingency tables. A statistically significant result was taken to be any result that had a two tailed p-value lower than p = 0.05.

In a follow-up a further sample question on eating fish from the contaminated lake was given to a random group.

The questionnaire

The questionnaire (Appendix A) which was filled out by each household obtained the sex and ages of all persons living at each address where there were people living at the time of the survey. These were obtained from the electoral register. It also obtained the details of all cancers, which had been diagnosed in the 10 years from 1995, including the type of cancer (site), the age at diagnosis and the year of diagnosis. In addition, the questionnaire asked for whether the person smoked cigarettes, whether they had worked at Trawsfynydd, fished in the Trawsfynydd lake or eaten fish from the lake.



Map of Trawsfynydd Nuclear Power Station (ringed in red) and the study area. Llan Ffestiniog is 3.6km and Gelli Lydan is 1.3km from the plant. Cwm Prysor is to the South of the lake but contributed few cases.

Results

Questionnaires were filled in from 260 addresses in Llan Ffestiniog, 121 addresses in or near Gellilydan and 21 from the farms in Cwm Prysor. The numbers of persons in these areas represent the base population for the analysis of cancer expectation and these are given in Table 1. Houses and farms where there was no one at home were revisited on a different day. The population in the study is believed to represent more than 90% of those living permanently in the area where the survey took place.

Table 1. Questionnaire responses.

Area	No of questionnaires	Persons
Llan Ffestiniog	260	640
Gellilydan	121	279
Cwm Prysor	21	59
Total area	402	978

The age and sex breakdown of the survey population is given in Table 2.

A proportion of houses were empty or were holiday homes. Two people refused to answer the questionnaire; one of these on the basis that there had been a cancer very recently and the person was too upset to discuss the issue. The survey included cancers that had been reported in people who were recently dead but who had lived at the address and were known to the occupants (relative). The number of these cases recorded in the cancers was two.

Table 2. Sex and age breakdown of the survey base population recorded in the questionnaires returned.

Age group	Males	Females
0-4	16	18
5-9	36	29
10-14	39	32
15-19	48	42
20-24	13	11
25-29	20	23
30-34	33	21
35-39	30	31
40-44	43	38
45-49	38	35
50-54	21	32
55-59	34	44
60-64	33	28
65-69	22	21
70-74	29	35
75-79	22	20
80-84	11	14
85+	2	14

The observed numbers of cancer in the two periods chosen are given together with expected numbers, SIRs, confidence intervals and p-values in Table 3. We have looked at cancer in all ages, but since there seemed to be many cancers in younger people; we also examined the risks in the age group 0-60 and 0-50. It is clear from the results that there is a significant excess cancer risk at all ages in the last three years 2003-2005 and that this effect is even greater in the younger people. For people below the age of 50 we see 15 times more cancer in women than would be expected on the basis of national figures for England and Wales.

The questionnaire asked whether those who developed cancer worked at the nuclear power station, fished in the lake or ate the fish from the lake. These fish are known to be contaminated with radioisotopes. It was perhaps significant that of the women under the age of 60 who were registered with breast cancer between 2003 and 2005, three ate fish from Trawsfynydd lake; one did not and one is dead and we do not know if she did or not. Details of these women are given in Table 4. The questionnaire also obtained smoking status.

Table 3. Trawsfynydd study cancer risk table; not including non-melanoma skin cancer.

Cancer	1996-2005; Obs/Expect	10 yrs SIR Poisson p-value	2003-2005 Obs/Expect	3 yrs SIR p-value*	95% Confidence Interval
All ages					
All maligs M	40/34.5	1.16	22/10.5	2.13 (0.002)	1.34, 3.29
All maligs F	27/30.6	0.9	16/9.18	1.74 (0.05)	1.03, 2.92
All maligs P	67/65	1.03	38/19.5	1.95 (0.005)	1.39, 2.74
F breast	10/7.7	1.3 (NS)	6/2.32	2.6 (0.03)	1.16, 5.79
Prostate	8/6.79	1.2 (NS)	5/2.03	2.5 (0.05)	1.01, 5.93
All leukemia	3/1.28	2.34 (NS)	3/0.384	7.8 (0.007)	
Leuk + lymph	4/2	2.0 (NS)	4/0.616	6.5 (0.003)	
mesethelioma	3/0.37	8.1 (0.005)	2/ 0.111	18.0 (0.005)	
pancreas	3/1.39	2.15 (NS)	2/0.417	4.8 (0.06)	
larynx	4/0.425	9.4 (0.0008)	0		
colon	7/4.1	7/4.1 (NS)	0		
0-60					
All maligs M	8/5.6	1.42 (NS)	3/1.68	1.8 (NS)	
All maligs F	14/8.66	1.62 (0.05)	11/2.6	4.23 (0.0001)	2.18, 7.16
All maligs P	22/14.3	1.54 (0.03)	14/4.28	3.3 (0.0001)	1.79, 5.92
F Breast	6/3.42	1.75 (NS)	5/1.02	4.9 (0.004)	2.02, 11.99
0-50					
All maligs M	2/0.7	2.9 (NS)	1/0.22	4.54	
All maligs F	8/1.08	7.47 (0.0001)	5/0.324	15.4 (0.00005)	
All maligs P	10/1.78	5.6 (0.00001)	6/0.544	11.3 (0.0001)	

Note: p-values in column 5 are Fisher Exact two-tailed for cells with less than 5; for small numbers and for the 10-year period, cumulative Poisson p-values are given for information.

Table 4. The 5 women under the age of 60 yrs diagnosed with breast cancer between 2003 and 2005. Expected number is 1.02 in the three years (0.3415 per year). SIR = 4.9; p = 0.004.

Case No	Age at diagnosis	Year of diagnosis	Area	Notes
41	36	2003	Ffestiniog	Dead
132	56	2003	Ffestiniog	Alive, smoked no fish
134	59	2003	Ffestiniog	Alive, smoked, ate lake fish
159	57	2005	Ffestinog	Alive, smoked, fished in lake, swam in lake, ate lake fish
329	57	2003	Gellilydan	Alive, non-smoker, worked at Trawsfynydd visitor centre, ate lake fish

In addition to the cancers recorded in Table 3, there were other cancers diagnosed in the 10-year period. These included cancer of the lung, stomach, thymus, cervix, brain, uterus, ovary, liver, bladder, skin, kidney and myeloma.

The survey also asked if anyone who had developed cancer ate fish from Trawsfynydd lake. The lake is used as a sports amenity and contains trout, which are caught by fishermen and are often eaten. The trout contain radionuclides and are therefore regularly monitored by the authorities. Following the survey, when we discovered there seemed to be a significant proportion of people with cancer who had eaten fish from the lake, a new survey was carried out to examine the background rate of fish eating in the whole population. In 100 people sampled there were 10 people who had at one time eaten fish from the lake. One of these we have included although she said she 'was not sure'. Three people in this group said they had eaten fish but no longer did.

Thirty-eight people were diagnosed with cancer between 2003 and 2005. Of these, 8 reported eating fish from the lake. If we use 10/100 as the background rate in the population then we would expect 3.8 of these to be fish eaters. Using Cumulative Poisson Tables we see that to find 8 fish eaters or less in this population, a relative rate of 2.1, has a probability of p = 0.04 and is therefore a statistically significant finding. One of these cases was a teenager 18yrs, who developed lymphoma and who was said to be an ardent angler who fished the lake regularly.

Discussion

Trawsfynydd is an ideal site to investigate the health risks of releases from nuclear power stations. This is because it has operated continuously between 1965 and 1993. After it stopped generating electricity in 1992, activities associated with its decommissioning continued to release radioactivity to the air and to the lake. It is isolated in a mountainous region of North Wales and has a well-defined local rural population to the north and north east large enough to provide a background cancer rate, which can be used to assess risk in the case of adult cancers, though not, of course, childhood cancer and leukemia. Additionally, in this local study, there is no large town in which would be the 5-10 or 10-25 km control region that would bias any assessment of fall-off of risk with distance, a serious con-

founding problem with concentric circle studies.

The effects of exposures to licensed releases from nuclear plants is increasingly of interest. Recently, the US Nuclear Regulatory Commission asked the National Academy of Sciences to organise a "state of the art" study on cancer risk in populations surrounding NRC licenses nuclear facilities to allay fears in these populations. As the NRC writes:

Nuclear facilities licensed by the US Nuclear Regulatory Commission (NRC) sometimes release very small amounts of radioactivity during normal operations. NRC regulations ensure plant operators monitor and control these releases to meet very strict radiation dose limits, and plants must publicly report these releases to the agency. Some communities are concerned about these releases' potential impact on the health of those living near those nuclear facilities. [24].

The advantages of the type of cross sectional cohort study presented here is that the population at risk is clearly defined as those who provided the sex and age breakdown numbers at the time of the survey. This is far more accurate than local census data for small areas which are not often easy to define in boundary terms and which have to be extrapolated across the intercensus interval. In addition, the cancer cases here are reported by those who were diagnosed or members of their families, thus reliance on official data is unnecessary.

The disadvantage is that cases are lost as we go back in time; people may move away and since cancer rates increase rapidly with old age, those who developed cancer and died are not there to answer questionnaires. The effect is clear for lung cancer, which has a high incidence to mortality ratio, and for which there has always been a very low apparent incidence rate in all the studies of this type we have carried out. The population leakage effect was seen in the studies we carried out in Carlingford, County Louth and in Burnham on Sea, downwind of the Hinkley Point nuclear site in Somerset [18, 19]. That study showed a doubling in breast cancer incidence, a finding that was later confirmed by the South West Cancer Intelligence Agency from its own figures giving support to the utility and general accuracy of the method.

Trawsfynydd is a "dirty" nuclear power station. As it has carbon dioxide, gas cooled graphite block reactors its releases to air are higher than most other types of nuclear reactor. In addition, all the liquid releases are discharged to lake where they have accumulated in the lake bed sediment [21]. Results of tabulated airborne radionuclide releases from UNSCEAR 2000 for the last year of full generation at Trawsfynydd, 1991, give 1,489,000GBq of radioactive noble gases and 0.28GBq of radioactive particles released to the air. If we assume this as the mean release then in the 26 years of operation the plant has released more than 37 x 10^{12} Bq of noble radioactive gases to the air downwind and 7GBq of radioactive particles, not to mention the other radionuclides, Tritium, Carbon-14, Uranium isotopes, Americium-241, Plutonium-239, Caesium-137, Strontium-90 and so forth [22]. CEGB surveys show significant accumulation of these radionuclides in the lake bed sediment of the so-called "hot lagoon".

Results show very clearly that the downwind population has suffered because of these exposures. This is most clear in breast cancer in the younger women below 60 where the rates were almost 5 times the expected. Breast cancer was studied also by Jay M Gould who used US national data to show that the rates were significantly higher in US Counties, which contained or were down wind of nuclear facilities [25]. We have studied breast cancer mortality near two other nuclear sites in the UK using official national ward level data purchased from the Office for National Statistics, Bradwell in Essex (this journal) and Hinkley Point, Somerset [16, 17, 26, 27] and in both cases have found a doubling in risk in those wards adjacent to contaminated estuarine or coastal sediment and /or downwind.

One question which arises is whether the origin of the cancer excess is not the power station but is exposure to radioactivity from Chernobyl. Large areas of North Wales were exposed to Caesium-137 from Chernobyl and restrictions were placed on the sale of sheep from contaminated areas. The study area was one of these, and therefore it is possible that the effects seen here are partly a result of Chernobyl exposures. However, cancer rates in North Wales have increased after Chernobyl far less than the levels seen in this study [28, 29]. Additionally we see a doubling of risk in those who ate fish from Trawsfynydd lake, which supports the conclusion that it is mainly a nuclear power station effect that is being seen.

These results are remarkable and relevant to political decisions about nuclear energy. The significant effects of internal exposure to fission products and uranium have been seen for some considerable time, and particularly since Chernobyl [30, 31] to be much greater than the current ICRP model predicts. In addition, since childhood leukemia is known to increase near nuclear sites, it is not unexpected that adult cancer rates will also be elevated and this is what these results show.

We suggest that adult cancer incidence near nuclear sites is studied with realistic protocols regarding the dispersion of the discharges, in particular (a) in local downwinders rather than in concentric circles where large towns may confound the radial distribution of risk and (b) near regions where measurements show that the radioactivity is accumulated e.g in those living near contaminated rivers, estuaries [15] or the sea [16,17, 26] and (c) without any pre-judgement of the expected excess risk based on the ICRP model, which may be quite unsafe for assessing risks from internal chronic exposures [12].

Ethics

No formal ethical permission was sought from Welsh government. Ethical guidelines of the Helsinki convention were applied. All householders visited were reassured that results would be anonymised and the final completed questionnaires destroyed after the data had been transferred to a database. Householders were asked to indicate if they would assist with further research or follow up. Most of the respondents did so.

Conflict of Interest

Neither of us has any conflict of interest. S4C Television Cardiff paid £800 toward the cost of the study.

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