Childhood cancer incidence in the vicinity of the Sutro Tower, San Francisco

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Abstract:
The Sutro Tower is a prominent feature on an elevated site in central San Francisco. It has been operating since about 1970, providing radio and TV signals for the San Francisco Bay area. There has been a long-standing concern about the health effects of this high-powered transmitter in the centre of a large urban population. A data-set is available that contains the US white childhood cancer cases from the period 1973-88 with residential locations. A number of previous studies have shown elevated cancer rates in residential populations living in the vicinity of RF/MW broadcast towers. The *a priori* hypothesis, that RF/MW radiation at residential levels of exposure causes cancer, is tested using this San Francisco data. The data was analysed in relation to geographic factors that influence the RF/MW exposure levels, cancer rates very close to the tower, a three-ring radial analysis, a detailed radial exposure assessment analysis and a cumulative radial analysis. All of the analyses support and confirm the hypothesis and eliminate potential confounding factors. This provides strong and conclusive evidence that RF/MW radiation is carcinogenic and that the Sutro Tower emissions result in highly significantly elevated cancer rates in children in San Francisco.
Key Words: Radiofrequency, microwave radiation, exposure assessment, childhood cancer.

Background: The radiofrequency/microwave (RF/MW) emissions from the Sutro Tower, in the heart of San Francisco, have been a long-standing public health concern. The City/County of San Francisco, Department of Public Health carried out a survey of childhood cancer in 1988 and found that in the Noe/Eureka Valley, the suburb to the east of the Sutro Tower, the childhood cancer rate from 1973-85 was 21 when 11.8 was expected. This is significantly increased, SIR=1.78. The suburb to the west of the Tower, East Sunset, had a non-significant elevation of childhood cancer SIR = 1.47, (1). Several other studies have found elevated adult and childhood cancer in residential populations living in the vicinity of RF/MW transmitters, (2-9). Hence there is considerable scientific evidence supporting the public concern.

Selvin, Schulman and Merrill (10) used a childhood cancer SEER derived data-base from San Francisco, for the period 1973-1988, to evaluate three statistical methods for clustering. The centre point for this study was the Sutro Tower. Their paper provides spatial maps of four cancers from US white children <21 years of age residing on the San Francisco Peninsula. The hilly topography of San Francisco provides the opportunity to evaluate the effect of geography on RF/MW exposure levels. Elevated sites exposed to the RF/MW signals can experience higher mean field intensities because they may be closer to the main beam. Areas behind hills or ridges can have a shadow effect, reducing the mean residential exposures.

The data allows for a simple high, middle and low exposure analysis, using the 2x2 analysis method to determine whether this reveals significant elevations and a dose-response. A radial ring analysis based on measured and theoretical radial RF/MW radiation patterns seeks to investigate the dose-response characteristics. A cumulative radial analysis to determine if the radial distance form the Sutro Tower provides a significant linear correlation trend with cancer.

The *a Priori* Hypothesis:

Because several previous studies have associated residential RF/MW exposure with adult and childhood cancers, there is a scientific basis for the *a priori* hypothesis that chronic exposure to RF/MW radiation causes cancers at residential exposure levels. In this study childhood cancer is used to evaluate the hypothesis.

The principles of causation applied here are derived from Hill (11) and Beaglehole, Bonita and Kjellström (12), namely, temporality, dose-response trends, strength of association, consistency, and biological plausibility. Temporality is essential because the exposure must occur before the disease develops. The Sutro Tower was established in about 1970 and the data in this study covers the period from 1973-88, following the producing of the public exposure to RF/MW from the Tower. Biological plausibility is helpful but not essential, (11). Cancer from RF/MW exposure is plausible if there is evidence of genotoxicity.

Dose-response trends and high strength of association can be sufficient for causation by themselves. When they coexist they produce very strong evidence of causation. The dose-response puts the question of causation in a very clear light, (11). In the absence of a correlated confounder, an unbiased dose-response relationship indicates causation, (12).

Biological Plausibility:

Cancer is biologically plausible if the disease agent is genotoxic. RF/MW radiation significantly enhances chromosome aberrations in many studies (14-32). Four of these studies show dose-response relationships (20, 21, 26, 30), and seven show significant micronuclei formation (18, 20, 21, 23, 26, 30, 32). Nine studies from five independent laboratories show direct DNA strand breakage (34-42). One of these studies shows a dose-response (35) and another shows an extremely significant DNA strand breakage, $p<0.0001$, at a very low exposure level, 0.0024 W/kg, (40). Two of the DNA studies (38,39) claim that their data does not show that RF/MW radiation produces DNA-strand breakage. However, their data shows significant DNA breakage followed by significantly enhanced DNA repair. There is highly substantial evidence that RF/MW is genotoxic and is therefore carcinogenic.

The Spatial childhood cancer data set:

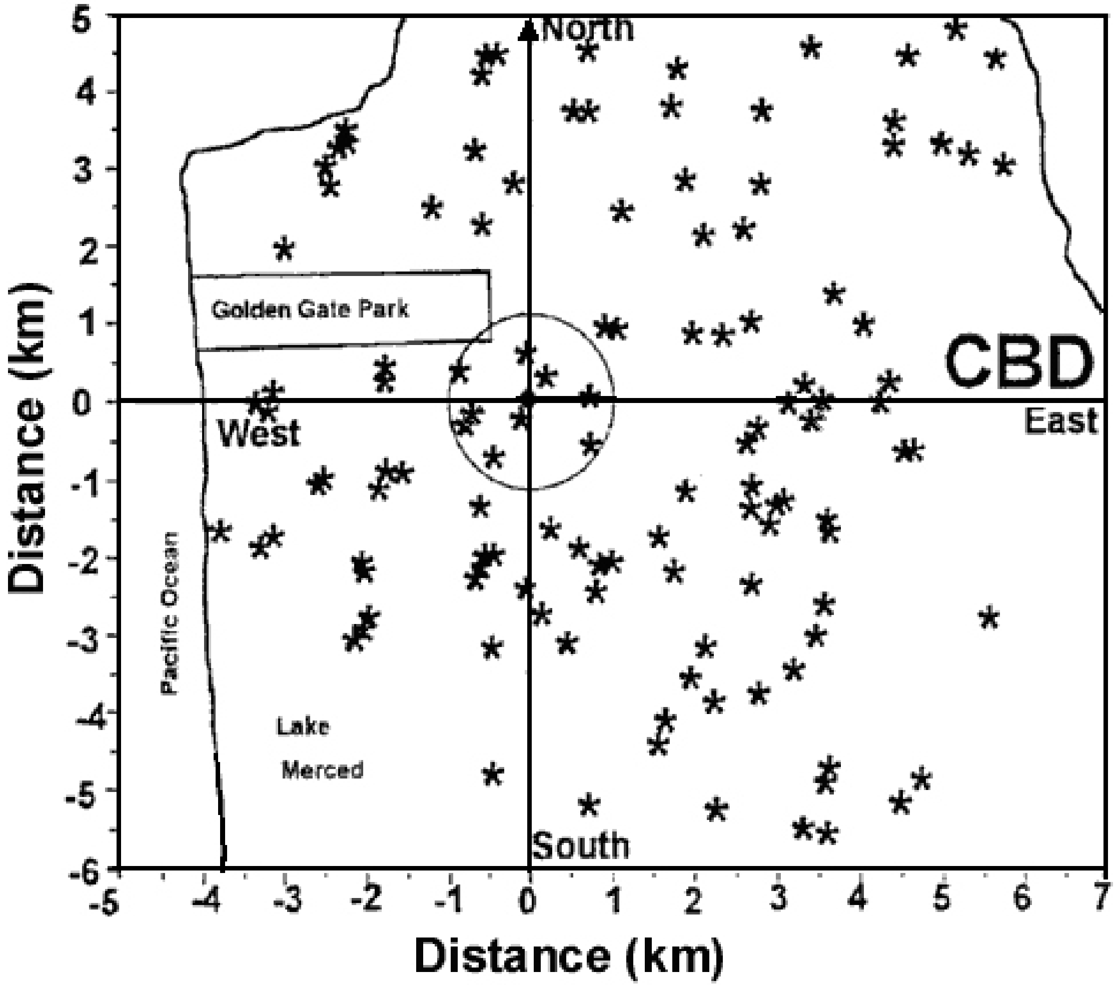
The cancer data-set provided by Selvin et al. (10) involves all the SEER registered US white childhood (aged <21 years) cancer incidence cases in San Francisco for the 16-year period 1973-1988. This data contained a total of 123 cases of childhood cancer from a population of 50,686 white children. This included 51 cases of leukaemia, 35 cases of brain cancer and 37 cases of lymphatic cancer. Selvin et al. estimated that these categories of cancer cover close to 50 % of all cancers.

Selvin et al. give maps of the spatial distribution of these childhood cancers in the San Francisco City area from 1973-1988. The residences of four types of cancer are provided on separate maps They include Hodgkin's Lymphoma, Non-Hodgkin's Lymphoma, Leukaemia and Brain Cancer. Each map was enlarged. The cancer case locations for each type of cancer were determined using a computer linked digitising pad. This formed a data-base of 123 cases with x- and y-co-ordinates,

[*text missing here....*]

All points were placed on a detailed street map of San Francisco to confirm that they corresponded to residential locations. The spatial uncertainty, based on the ability to locate the centre of the mapped points and normal measurement uncertainty, is estimated as less than ±100m. The combined map for all 123 cancer cases is shown in Figure 1.

Figure 1: Spatial map of white childhood (<21 years) cancer for San Francisco, 1973-88, from Selvin et al. (10). The Sutro Tower is the solid circle with the north-south and east-west axes passing through it. The circle is a 1km ring around the Sutro Tower. CBD: Central Business District.



Cancer rates in close proximity to the Tower

Figure 1 shows that there are 9 cancer cases within the 1 km ring around the Tower. This consists of 5 brain cancers, 2 leukaemias and one of each of the Lymphomas. The two cancer cases within 500 m of the Tower are brain cancers. A visit to the site revealed that there were suburban streets in the vicinity of the Tower but they are separated by open spaces. The Sutro Tower site itself is on open ground. The nearest houses are about 100m from the tower. The study area was confined to the San Francisco Peninsula, north of about Daly City. The furthest cancer case from the Sutro

Tower was at 7.1km. Along the eastern side the coastline is close to an 8km circle from the Tower. Hence the limit of the study area was chosen to be an 8km circle around the tower.
This area includes ocean areas, particularly along the west coast, as well as the central business district, the port area, parks and reserves such as the Golden Gate Park and Lake Merced, a detailed street map was used to calculate the proportion of each radial ring that contained residential housing. This factor was called the Residential Density Factor (RDF). The RDF varied from 40% in the vicinity of the Tower and 50% in the outer ring, to a maximum of 93% at a radius of 2.6 to 3.5km. This ring it is almost entirely residential but it contains the Golden Gate Park in one segment. Using these factors the total population of white children for the study period (50,686) was distributed through the radial rings to form the Estimated Population, Table 1.
In Table 1 each symptom table sets out the number of cases, the incidence rate per 100,000 p-yrs, **[*text missing here....*]** reference group. The Reference Rate is given in brackets next to the incidence label. The cumulative row is the cumulative relative risk starting with the reference group (RRcum = 1.0 at 4.8km), and progressing inwards towards the tower ring-by-ring, adding the cases and the population to form the cumulative RR. This is primarily independent from the radiation pattern assumptions as the fitted trend averages over the intervals.
Since the hypothesis relates to the RF/MW exposure from the Sutro Tower, a reference population that lived furthest from the Tower, >4.8km, was chosen. This group contains an Estimated Population of 27,486, 54% of the total population. The children in this population had 6 brain cancer cases and 19 All Cancer cases. This gives a reference incidence rate for the 16 years of the study data of 1.365/100,000 p-yrs for brain cancer and 4.321/100,000 p-yrs for All Cancer.
For the 2 brain tumor cases in the 100 to 500m ring around the Tower their estimated population is 114 and hence their incidence is 110.1/100,000 p-yrs. All 2x2 statistical calculations were carried out using the EPI INFO 6 package. This gives a Relative Risk of RR = 80.37, 95%CI: 16.39-394, p=0.00046, using the Fisher Exact value. For the 1km ring (0.1-1 km) there are 5 brain cancer cases in an estimated population 736. This yields RR = 31.12, 95% CI: 9.52-101.74, p=0.0000048. For the All Cancer cases in the 0.1-0.5 km ring RR = 25.38, 95%CI: 5.98-107.7, p = 0.00337. For the 0.1-1km ring, RR= 17.69, 95% CI: 8.03-38.97, p<10-7.
These observations, through their strength of association, their level of significance and their dose-response relationships, give support for the hypothesis.

Geographic Patterns:
With knowledge of local topography and city layout there are clear geographical patterns in the data shown in Figure 1. The east/west line of cancers to the northeast of the tower is along a ridge that is directly exposed to the tower. In contrast, the valley to the north of the line is not directly exposed and has no cancer cases. To the southeast of the tower there is the Twin Peaks Reserve, with no houses, and a shielding shadow, associated with an absence of cancers. There is a tendency for the data to appear in radial circles and local clusters. The standard RF radial pattern has undulating high and low exposure rings produced by the antenna vertical radiation pattern, Figure 2.

Figure 2: A typical Relative Field for a UHF RF/MW broadcast antenna from Hammett and Edison *(42)*

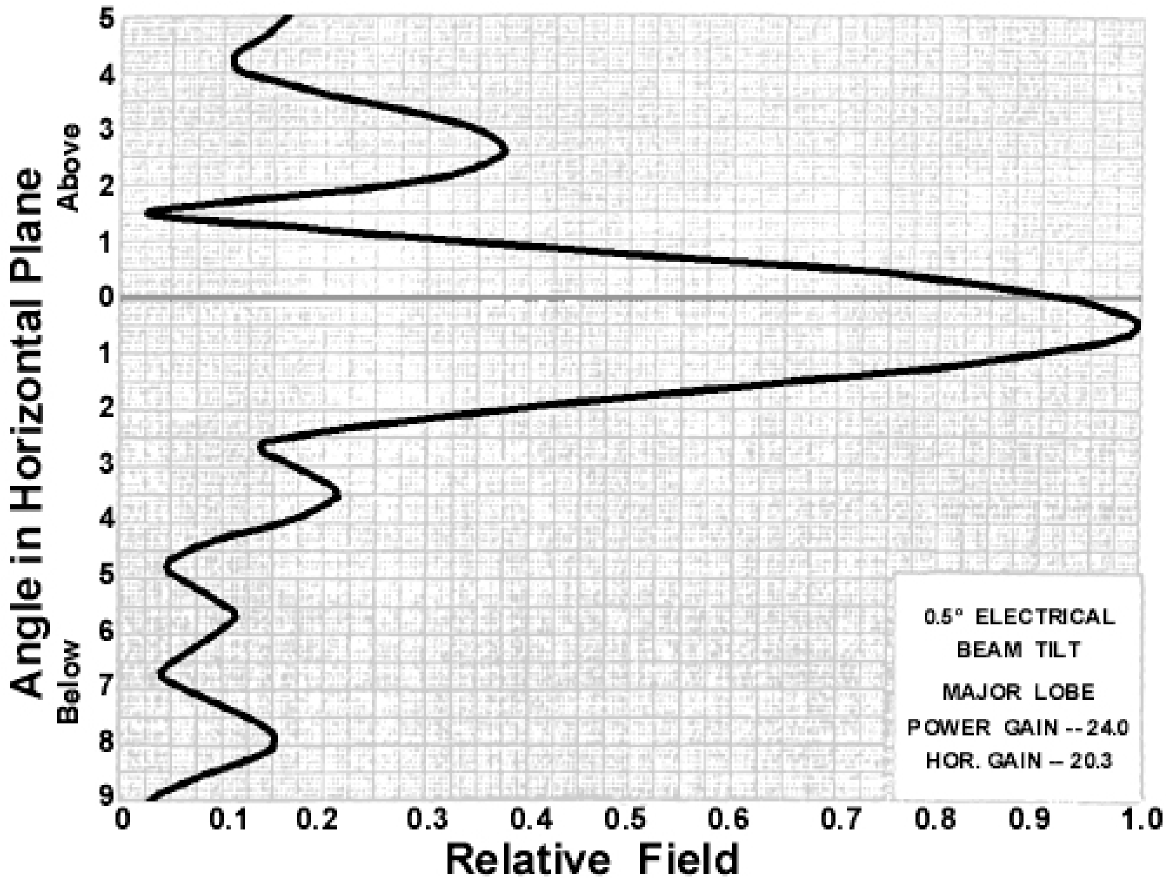


Table 1: Radial rings, with estimated population, Risk Ratios and Cumulative Risk Ratios, for white childhood Brain Cancer, Leukaemia, Lymphoma, and All Cancer, in association with RF/MW exposure from the Sutro Tower, San Francisco. RDF: Residential Density Factor. Incidence is given per 100,000 p-yr (Reference Rate from >4.8 km).

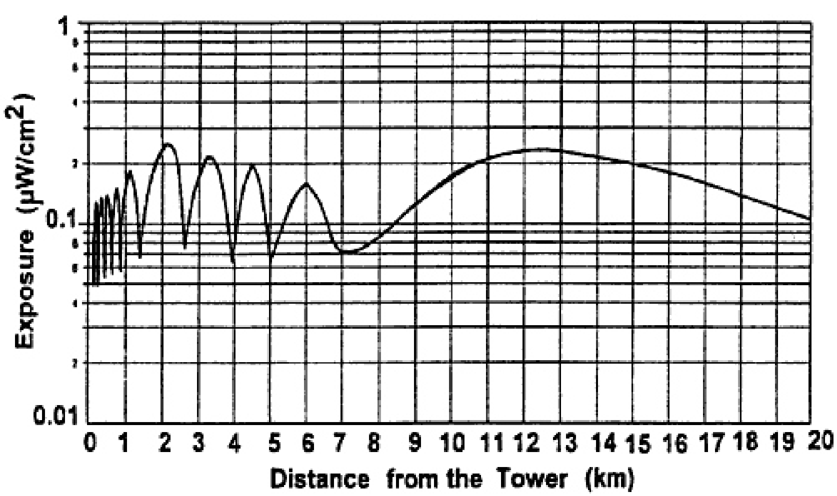
Distance (km)	0.1-0.5	0.5-0.7	0.7-1.0	1.0-1.2	1.2-1.6	1.6-1.8	1.8-2.4	2.4-2.6	2.6-3.5	3.5-3.7	3.7-4.8	4.8-5.4	5.4-6.9	>6.9
Est. Population	114	170	452	442	1166	724	2712	1088	6038	1447	8846	4704	13091	9691
RDF	0.40	0.6	0.75	0.85	0.88	0.9	0.91	0.92	0.93	0.85	0.80	0.65	0.6	0.5
Estimated Mean Exposure, µW/cm^2	0.65	0.075	0.30	0.035	0.065	0.010	0.07	0.008	0.06	0.005	0.045	0.003	0.01	0.004
Cancers														
Brain Cancer Cases	2	0	3	0	2	0	6	0	7	1	8	1	5	0
Incidence (1.365)	110.10	0.0	41.45	0.0	10.72	0.0	13.83	0.0	7.25	4.32	5.65	1.33	2.39	0.0
Relative risk	80.37	0.0	30.48	0.0	7.86	0.0	10.14	0.0	5.31	3.16	4.14	0.97	1.75	0.0
Cumulative RR	3.16	2.99	3.00	2.75	2.78	2.65	2.69	2.24	2.30	1.82	1.77	1.00	1.01	0.0
Hodgkin's Cases	0	0	1	0	0	0	5	0	8	0	8	0	2	2
Incidence (0.910)	0.0	0.0	13.82	0.0	0.0	0.0	11.52	0.0	8.28	0.0	5.65	0.0	0.95	1.29
Relative Risk	0.0	0.0	15.19	0.0	0.0	0.0	12.67	0.0	9.10	0.0	6.21	0.0	1.05	1.42
Cumulative	3.52	3.53	3.54	3.44	3.47	3.55	3.61	3.06	3.14	2.18	2.27	1.00	1.21	1.42

Non-Hodgkin's Cases	0	0	1	0	0	0	1	0	4	0	4	1	0	0
Incidence (0.227)	0.0	0.0	13.82	0.0	0.0	0.0	2.30	0.0	4.14	0.0	2.83	1.33	0.0	0.0
Relative Risk	0.0	0.0	60.77	0.0	0.0	0.0	10.14	0.0	18.21	0.0	12.43	5.84	0.0	0.0
Cumulative	5.97	5.98	6.00	5.50	5.55	5.69	5.77	5.51	5.65	3.64	3.78	1.00	0.0	0.0
Leukaemia Cases	0	0	2	0	2	1	5	1	15	2	15	0	8	0
Incidence (1.819)	0.0	0.0	27.63	0.0	10.72	8.64	11.52	5.74	15.53	8.64	10.60	0.0	3.82	0.0
Relative Risk	0.0	0.0	15.19	0.0	5.90	4.75	6.33	3.16	8.54	4.75	5.83	0.0	2.10	0.0
Cumulative	3.46	3.46	3.48	3.37	3.40	3.34	3.32	3.14	3.14	2.27	2.18	1.00	1.21	0.0
Leuk+ Lymph Cases	0	0	4	0	2	1	11	1	27	2	27	1	10	2
Incidence (2.957)	0.0	0.0	55.27	0.0	10.72	8.64	25.35	5.74	27.95	8.64	19.08	1.33	4.77	1.29
Relative Risk	0.0	0.0	18.70	0.0	3.63	2.92	8.58	1.94	9.45	2.92	6.45	0.45	1.62	0.44
Cumulative	3.67	3.68	3.69	3.56	3.59	3.59	3.60	3.30	3.33	2.35	2.33	1.00	1.11	0.44
`All Cancer" Cases	2	0	7	0	4	1	17	1	34	3	35	2	15	2
Incidence (4.321)	110.10	0.0	96.72	0.0	21.45	8.64	39.18	5.74	35.19	12.95	24.73	2.66	7.16	1.29
Relative Risk	25.38	0.0	22.39	0.0	4.96	2.00	9.07	1.33	8.15	3.00	5.72	0.62	1.66	0.30
Cumulative	3.51	3.46	3.47	3.30	3.33	3.29	3.31	2.96	3.00	2.18	2.15	1.00	1.08	0.30

In Figure 1 there is a distinct arc of cancers about 4.5km to the SE of the Tower. Assuming a net height of the antennas on the Tower in relation to the ground level, of 460m, then this group of cancer cases corresponds to an antenna angle of 5.8°. This is close to the second peak below the main beam in Figure 2. The ring between 3.7 to 4.8 km contains 35 childhood cancer cases corresponding to RR = 5.72, 95%CI: 3.28-10.0, using all data from beyond 4.8 km as the reference group, Table 1.

The Relative Field peaks at 0.5, 3.5, 5.7, 7.9, 10.1 and 12.3°. With the assumption of antennae at 460m, these peaks correspond to ground level positions at 52.7, 7.5, 4.6, 3.3, 2.6 and 2.1 km from the tower. The actual exposure intensity is a function of the square of the Relative Field and the inverse square of the distance along a beam. This results in the ground level peaks being closer to the Tower, especially for the remote peaks. These adjustments are taken into account by the radial UHF pattern in Figure 3.This shows the main beam peak at 12.5km and the side-lobe peaks at 6, 4.5, 3.2, 2.2 and 1.1 km.

Figure 3: Ground level exposure for a typical UHF TV broadcast signal, from an antenna pattern from Hammett and Edison (42), for a 18 MW EIRP transmitter at 460m AGL, for a flat surface.



In Figure 1 there are distinct rings containing cancer clusters around 2.4, 3.1, 4.3 and 6 to 6.5km. This strongly suggests that the cancer clusters outside a 2km radius are closely related to the peaks of RF/MW exposures from the Sutro Tower UHF antennas, Figure 3. Because the antenna pattern depends on the carrier frequency, the range of transmission frequencies tends to smooth the signals' oscillations. This makes slightly broader peaks and slightly reduces the troughs.

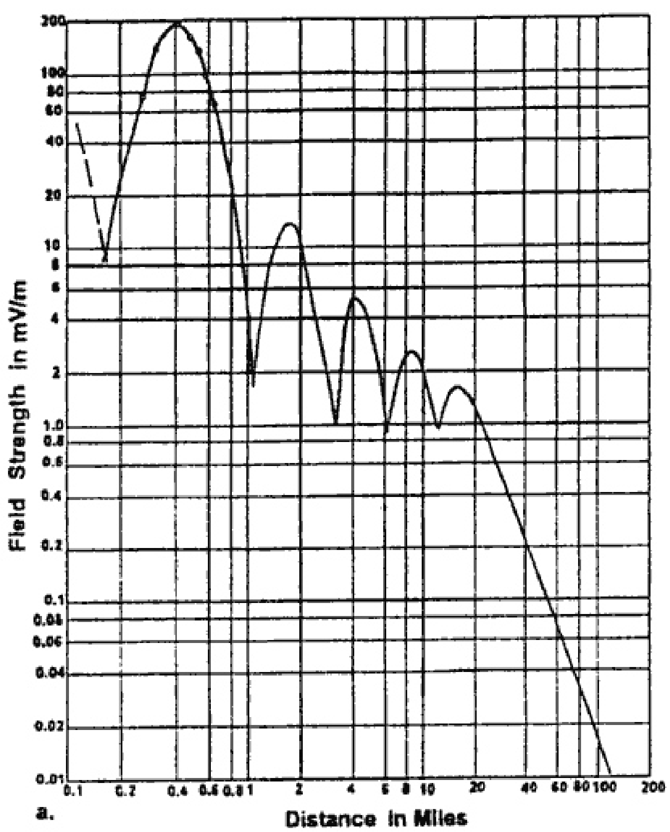
Radial RF/MW exposure patterns:

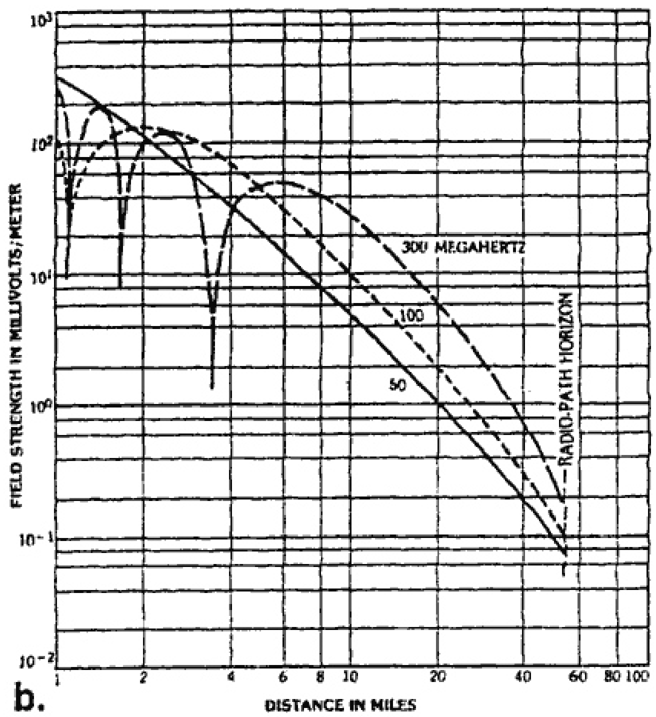
During the study period the Sutro Tower had about 1000kW of VHF/FM (54-192MHz) signals and 18,300kW of UHF TV stations (506-788MHz). The 977ft high transmission tower is on a hill that is 921ft high. This places the top of the tower at 1898ft (577m) above sea level. The majority of the antennas are within 220ft (67m) of the top of the tower. With the land around the tower varying from near the sea level to over 100m the relative heights of the antennas above the ground vary from about 400 to 570m (42).

These different broadcast frequency bands have distinctly different radial patterns. The VHF band has high peaks near the tower and they decline relatively quickly with radial distance and in an [*text missing here...*]

Figure 4. This VHF form of the ground level exposures is confirmed by a broadcast engineering handbook (44).

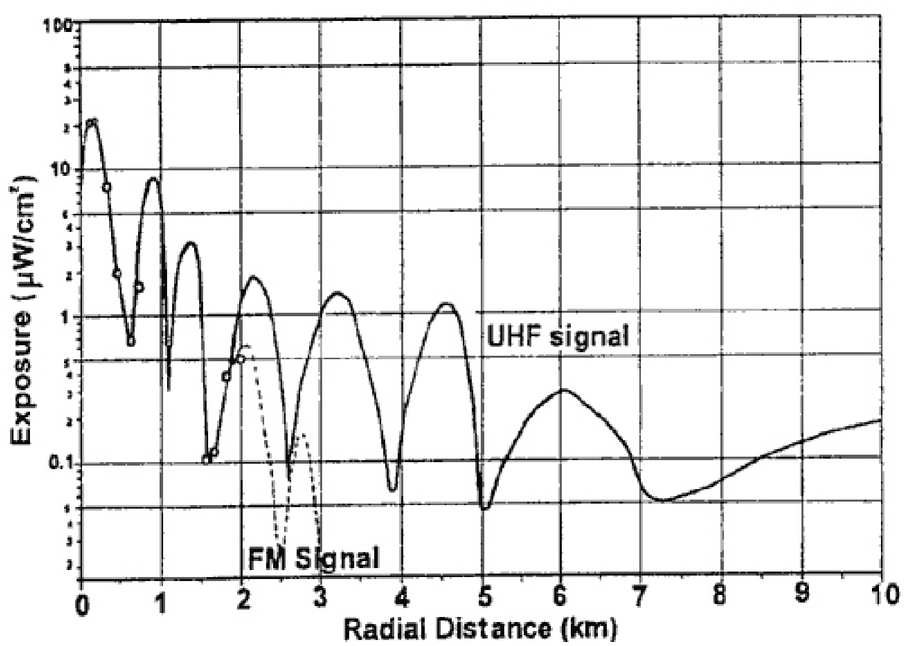
Figure 4: Ground level radiation pattern for (a) the 44 MHz (VHF) signal from the Empire State Building in New York City, Jones (43) by merging his figures 6 and 8, and (b) a theoretical set of 1 kW antenna at a height 1000ft and a receiver at a height 30ft, Jordon (44).





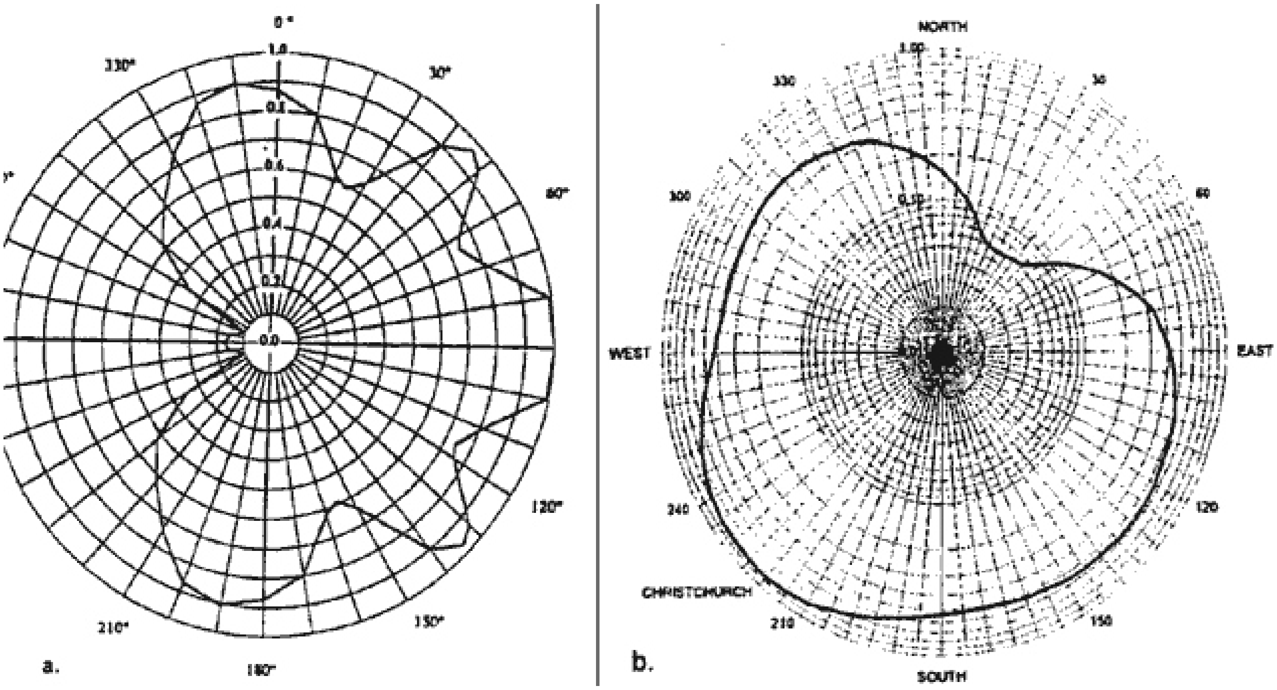
In contrast to the undulating declining VHF signal, the UHF antennas have a stronger ability to focus their signals towards the horizon with most of their energy in the main beam, as shown in Figure 3. Using the 10 readings provided by Hammett and Edison (42) and fitting curves to them to approximate the combination of figures 3 and 4a, results in the radial pattern given in Figure 5.

Figure 5: The measured and estimated power density (exposure in µW/cm^2) with distance from the Sutro Tower. Circles show measurements from Hammett and Edison (42).



Horizontal antenna patterns are also important since signals can be directed towards large population areas by design and choice of antennas, Figure 6.

Figure 6: Horizontal antenna radiation patterns showing the relative field strength for, (a) UHF Digital TV (linear scale) from the Sutro Tower (42), and (b) 99MHz VHF for 8 dipole array (logarithmic scale), Ouruhia transmission site, Christchurch, New Zealand.



In San Francisco the large majority of the population is on the eastern half of the north/south line through the Tower, Figure 1. A small population and little land is to the west. Figure 6 shows that it was the intention to direct the digital TV signal towards the eastern sector and this is a common approach around the world. It is highly likely that the original FM and TV signals from the Sutro Tower were similarly directed. The large majority of households in San Francisco, Marin County, Richmond, Berkeley, Oakland, San Jose and Silicon Valley are in the north/east/south sector. Dividing a 4km circle around the Tower into east and west sectors with a north/south line through the Tower, there are 37 cancer cases in the 4km wide western sector, and 43 in the eastern sector. This suggests that if RF/MW enhances the childhood cancer then the horizontal exposure pattern could have had a small influence on it.

Three-ring radial analysis:

Three rings were chosen to represent high, middle and low exposure populations, using 1km and 4.8km as the cut-off points. The results are summarized in Table 2 for the high vs low and Table 3 for the middle vs low comparisons. "n" is the number of exposed cancer cases in the upper groups. The Estimated Populations for each group are given in brackets in the heading.

Table 2: The 2x2 analysis comparing the High Exposed Group (<1 km, 736) cancer rates with the Low-exposed group (>4.8 km, 27486) in relation to the RF/MW exposures from the Sutro Tower.

Cancer Type	n	RR	95%CI	Chi Squ. p-value

Non-Hodgkin's Lymphoma	1	37.4	2.34-596	3.95	0.0515
Hodgkin's Lymphoma	1	9.3	1.04-83.4	1.08	0.124
All Lymphoma	2	14.9	2.90-76.9	9.76	0.0130
Leukaemia	2	9.3	1.99-43.9	6.05	0.0266
All Leukaemia/Lymph.	4	11.5	3.76-35.2	21.65	0.00083
Brain Cancer	5	31.1	9.52-101.7	79.54	$<<10^{-7}$
All Cancer	9	17.7	8.03-39.0	96.29	$<<10^{-7}$

The Chi Squared and p-values were derived from the Mantel Haenszel estimate unless the case element is less than 5. Then the Yates corrected Chi Squired value is given, along with the Fisher Exact p-value, as recommended by the EPI INFO 6 software. The sample sizes for the Leukaemia and Lymphoma data is very small. Even so, all of the relationships are significant except for Hodgkin's Lymphoma. All of the Relative Risks show strength of association which magnitudes between 9.3 and 37.4. For Leukaemia/Lymphoma, Brain Cancer and All Cancer the Relative Risks are extremely significantly elevated ($p<0.001$). For Brain Cancer and All Cancer the significance is so high, it is beyond the limit of the software packages range.

Table 3 shows the Middle vs Low exposure analyses. In Table 3 all of the case elements were greater than 5 and therefore the Mantel-Haenszel estimates were used. All of these Relative Risks are extremely significantly elevated because $p<0.001$, except Non-Hodgkin's Lymphoma which is highly significant, $p=0.0042$.

The data analysis in Tables 2 and 3 shows that with the low exposure reference group having RR = 1.0, every cancer type shows a dose response increase from low to middle and to high exposures. For example for All Cancer RR = 10, RR = 6.12 and RR = 17.69 from low, middle and high exposures.

Table 3: The 2x2 analysis for the Middle Group (1.0-4.8 km, 22463) cancer rates compared with the low-exposure outer group (>4.8 km, 27486) in relation to the RF exposures from the Sutro Tower.

Cancer Type	n	RR	95%CI	Chi Squ.	p-value
Non-Hodgkin's Lymphoma	9	11.01	1.39-86.9	8.19	0.0042
Hodgkin's Lymphoma	21	6.42	2.21-18.71	15.39	0.0000872
All Lymphoma	30	7.34	2.85-18.92	23.49	0.0000013
Leukaemia	41	6.27	2.94-13.37	29.69	0.0000001
All Leukaemia/Lymph.	71	6.68	3.70-12.07	53.19	<0.0000001
Brain Cancer	24	4.89	2.00-11.97	14.88	0.000114
All Cancer	95	6.12	3.74-10.01	67.94	<0.0000001

Mean direct exposures for these three groups were obtained from Figure 5 as 0.1, 0.5 and 3$\mu W/cm^2$. A Least Squares Fit linear trend has a threshold for significance of $t=12.706$ for $p=0.05$. For Brain Cancer is the $t = 116.314$, showing an extremely significant dose-response relationship with mean exposure to RF/MW radiation.

This data, including extremely significant elevated Relative Risks and a consistent dose-response increase for every cancer type, adds considerable support for the hypothesis that RF/MW is causally related to cancer.

In order to extend the evaluation of the Hypothesis two independent radial analyses were carried out. The first used the best estimates of the actual/theoretical RF radial pattern from measurements and fitted curves and compared the radial ring cancer rates with the alternating high/low exposure estimates. The second approach was to calculate the cumulative relative risks from the outer ring, reference groups, towards the tower. This latter analysis is totally independent of the estimated exposure patterns and is an independent check that the cancer is directly caused by the RF/MW [*Text missing here....*]

Detailed radial ring analysis:
Radial rings were selected using the alternating high and low exposures in Figure 5. The 14 chosen rings are detailed in Table 1. Each ring was allocated cancer cases, residential populations and a mean RF/MW exposure level. The cancer cases were selected using the digitised data-base. The residential population was estimated by distributing the given total population of 50,686 white children (<21 years) evenly over residential areas. The proportion of each ring that was residential was calculated using a detailed street map. This resulted in a residential density factor (RDF) as listed in Table 1. For each ring the childhood cancer incidence (per 100,000 p-yrs) was calculated and the Relative Risk (RR) was calculated using the reference incidence from those living beyond 4.8 km.
The Mean Residential Exposure (MRE) was estimated from the Mean Direct Exposure (MDE) derived from Figure 5. Because buildings significantly reduce the strength of the RF/MW signal, mean residential exposures are much smaller than the direct exposure at the distance of the residence. McKenzie et al. (45) report a direct measurement of 3 μW/cm2 on the roof of a dwelling near a radio/TV tower in North Sydney, Australia. At street level the signal was 0.066μW/cm^2 and inside the house it was 0.017μW/cm2. These give reduction factors of 45 and 176 respectively. Based on an average weekly activity of being inside at home for 108 hours, outside at home for 20 hours and away from home for 40 hours. Assuming that the away from home exposure is the same as the inside exposure. Using much more conservative street level and inside factors of 5 and 50 results in a mean REF of 0.041. This is rounded up to REF = 0.05 for this study. MRE=0.05 x MDE is likely to overestimate the mean residential exposure.

Exposure Trend Analysis:
The RR vs mean personal exposure for each radial ring was calculated and least squared fit trend line fitted. The significance of the trends are summarized in Table 4.

Table 4: Trend analyses for Sutro Tower exposure levels vs Relative Risks.

		RR vs Exposure		
	Corr Coef	T-value	df	p-value
Brain Cancer	0.9949	24.190	7	$<10^{-6}$
Non Hodgkin's Lymp.	0.9798	6.923	3	<0.01
Hodgkin's Lymphoma	0.8315	2.593	4	0.06
Leukaemia	0.9508	7.518	7	<0.0001
Leukaemia/Lymphoma	0.9438	8.077	9	<0.00001
All Cancer	0.8821	7.408	10	<0.00001

Despite the limited number of data points, the exposure based trends are all significant expect for Hodgkin's Lymphoma. For brain cancer and all cancer the trend is extremely significant, as are all trends for the cumulative distance related trend. The All Cancer, Brain Cancer and Leukaemia/Lymphoma exposure dose-response graphs are shown in Figures 7-9. There is considerable scatter around the LSF fitted trend lines, due primarily to the small overall case sample size. Trend significance was determined using the t-value derived from the correlation coefficient, n-2 degrees of freedom and a two-tailed t-test.

Figure 7: All Cancer Risk Ratio for Childhood Cancer as a function of estimated radial group mean personal exposure to RF/MW radiation from the Sutro Tower, San Francisco, using the spatial childhood cancer data presented in Selvin et al. (10). The dose-response relationship is extremely significant.

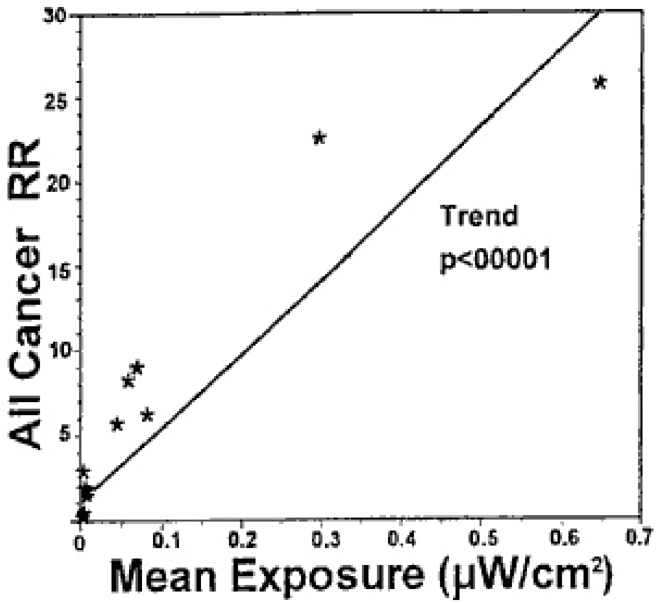


Figure 8: Brain Tumor Risk Ratio as a function of estimated radial group mean personal exposure to RF/MW radiation from the Sutro Tower, San Francisco, using the spatial childhood cancer data presented in Selvin et al. (10). The dose-response relationship is extremely significant.

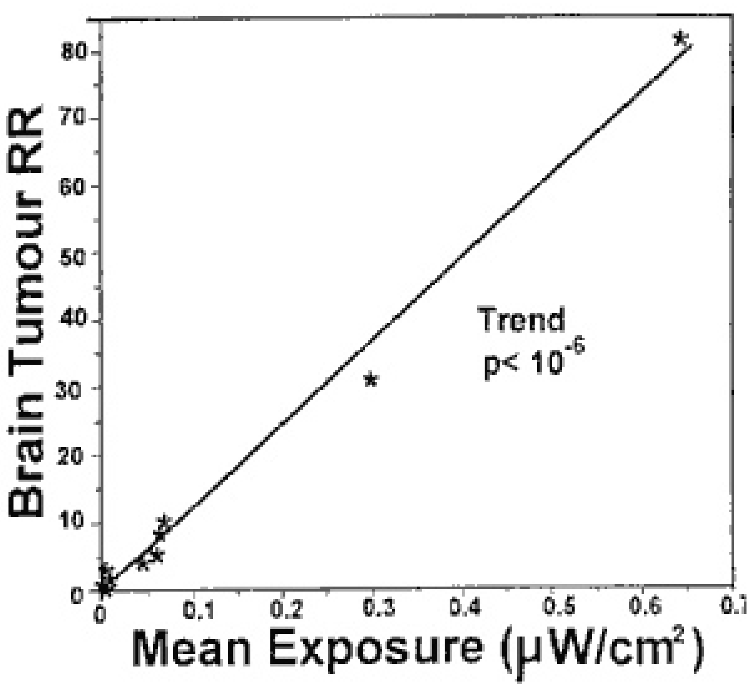


Figure 9: Leukaemia/Lymphoma Relative Risk as a function of estimated radial Personal Mean Exposure to RF/MW radiation from the Sutro Tower, San Francisco, using the spatial childhood cancer data presented in Selvin et al. (10).

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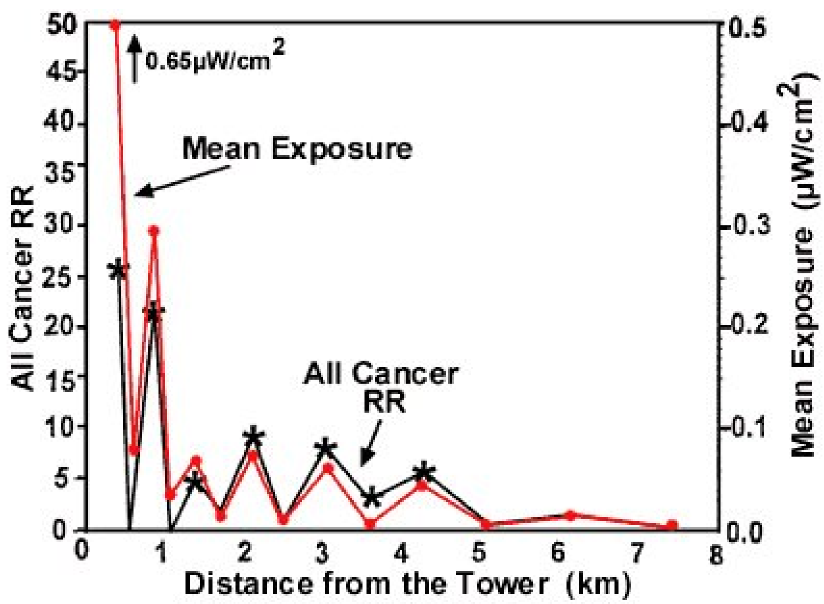
The dose-response relationships for the three cancers graphed are extremely significant. Figure 10 shows the radial All Cancer RR and Personal Mean Exposure as a function of radial distance from the Sutro Tower. Provided that the exposure estimated are approximating real exposure patterns, this shows that the radial variations are highly matched, discounting all confounders, and thus proving a causal relationship. In order to check this, a radial analysis that does not depend on the shape of the radial exposure pattern was carried out.

Figure 10: The radial All Cancer Risk Ratio and the mean residential RF exposure as a function of radial distance from the Sutro Tower, San Francisco.



These radial patterns, with the cancer rate closely following the undulating exposure pattern give strong confirmation of the hypothesis. This shows conclusively that the cancer is caused by the RF/MW emissions from the tower with no plausible confounders.
The 2x2 analysis for all the High vs all the low rings was carried out using a cutoff point of 0.02μW/cm², Table 5. This exposure level is equivalent to a direct outdoor exposure of 0.4μW/cm². This dichotomy identifies 52% of the population as "exposed" and 48 % as "unexposed".

Table 5: All Exposed to >0.02μW/cm2 (19940) and all exposed to <0.02μW/cm² (30745). The cut-off point is equivalent to a direct outdoor exposure of 0.4μW/cm².

Cancer Type	N_{high}	N_{low}	RR	95% CI	Chi Squ.	p-value
Non-Hodgkin's Lymphoma	10	1	15.42	1.97-120.4	12.26	0.0004627
Hodgkin's Lymphoma	22	4	8.48	2.92-24.61	22.34	0.0000023
All Lymphoma	32	5	9.87	3.85-25.32	34.49	<10-7

Leukaemia	39	12	5.10	2.62-9.57	29.49	0.0000001
All Leuk/Lymphoma	71	17	6.44	3.79-10.93	63.13	$<10^{-7}$
Brain Cancer	28	7	6.17	2.69-14.12	24.26	0.0000008
All Cancer	99	24	6.36	4.07- 9.93	87.47	$<10^{-7}$

All cancer types are extremely significantly increased, supporting the causal relationship.

Cumulative radial analysis:
Starting with the assumption that the group further than 5 km is the reference group, the cumulative incidence rate and Relative Risk was calculated from the outer ring to the inner ring in distance increments of 0.5 km. This result is independent of the exposure ring assumptions since a uniform radial increment is used. The Non-Hodgkin's Lymphoma cases were so small (N=11), there were none outside the 5km cut-off point. The one case at 4.85km was used to put one case into the reference group. This was accomplished by using a 4.8 km cut-off for this cancer type.

Table 6: Trend analyses for the cumulative Relative Risk as a function of distance from the Sutro Tower, using 0.5 km increments.

	Corr. Coef.	T-value	df	p-value
Non Hodgkin's Lymp.	0.8774	4.839	8	<0.005
Hodgkin's Lymphoma	0.9612	11.560	12	<0.000001
Leukaemia	0.9677	12.741	12	<0.000001
Leukaemia/Lymphoma	0.9670	12.592	12	<<0.000001
Brain Cancer	0.9912	30.660	12	<<0.00000001
All Cancer	0.9778	15.485	12	<<0.000001

Three examples of these cumulative trends for All Cancer, Brain Cancer and Leukaemia/Lymphoma are given in Figures 11-13.

Figure 11: Cumulative Relative Risk for All Cancer as a function of radial distance from the Sutro Tower, San Francisco.

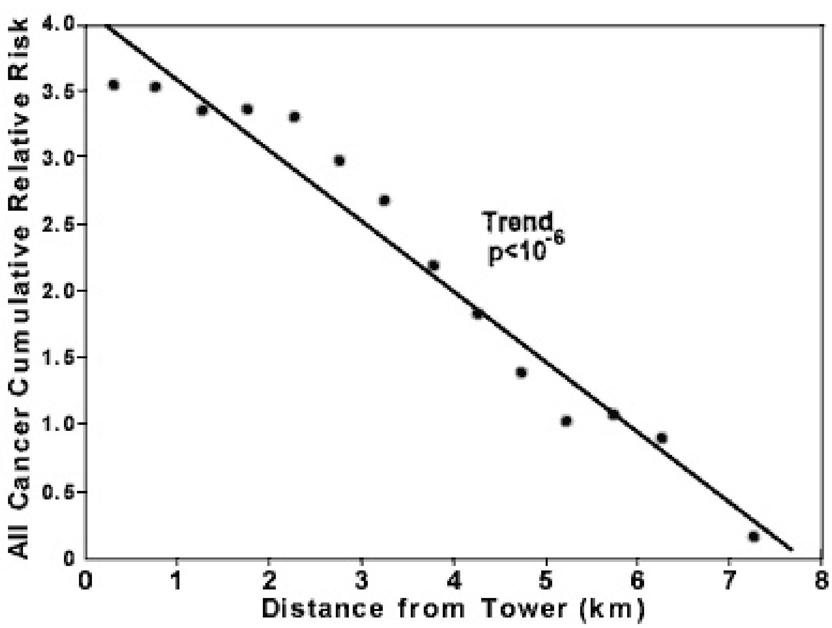


Figure 12: Cumulative Relative Risk for Brain Cancer as a function of radial distance from the Sutro Tower, San Francisco.

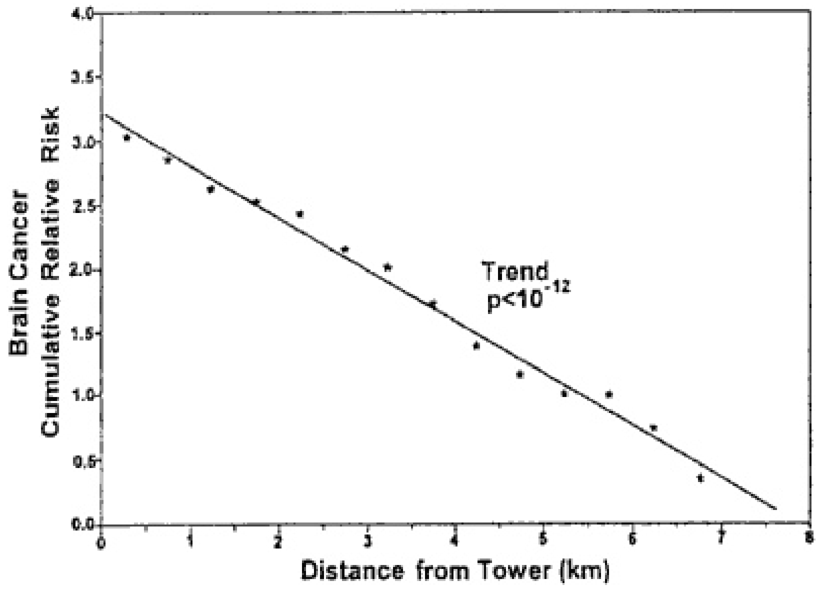
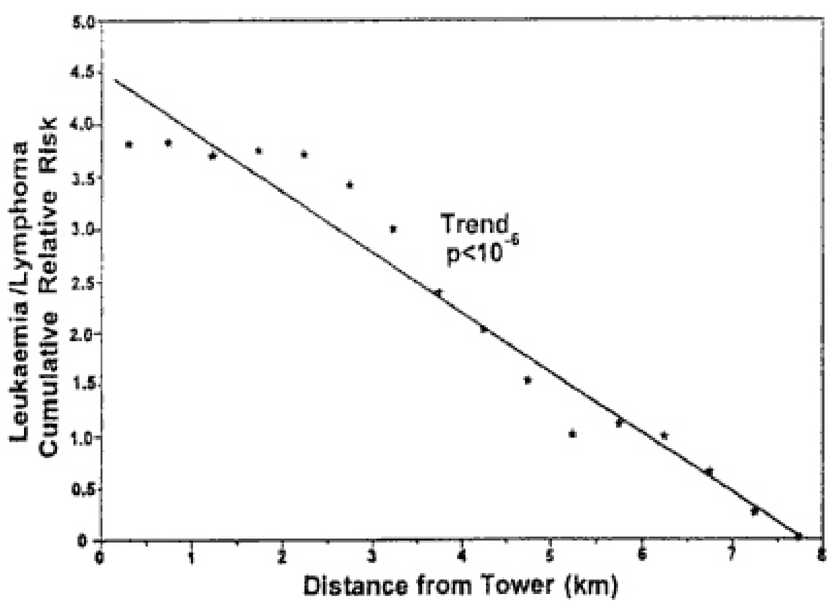


Figure 13: Cumulative Relative Risk for Leukaemia/Lymphoma as a function of radial distance from the Sutro Tower, San Francisco.



The cumulative trend analyses show that all trends are extremely significant and point solely to the Sutro Tower as the cause of the cancers. Hence there are no plausible confounders. This gives comprehensive, independent and direct confirmation of the hypothesis that the RF/MW radiation from the Sutro Tower causes cancer in children living in San Francisco. This confirmation also shows that RF/MW radiation is a carcinogen at non-thermal chronic exposure levels

Summary and Conclusions:

There are extremely high and significantly elevated childhood cancer rates in populations living very close to the Sutro Tower. Around the Tower there are geographic cancer clusters related to the ways in which topography influences the RF/MW exposures from the Tower. The significance and dose-response from the 3-ring analysis, the detailed radial ring analysis and the cumulative radial analysis, all provide a consistent and unbiased support for the hypothesis. Taken together, the analysis of this data-set strongly and comprehensively confirms the *a priori* hypothesis that the chronic exposure to RF/MW radiation causes cancer at residential exposure levels. There is robust evidence that RF/MW radiation is genotoxic. This study confirms that RF/MW is carcinogenic with a Lowest Observed Adverse Effect Level (LOAEL) of zero chronic mean exposure, consistent with RF/MW radiation being a genotoxic disease agent.

Although this study uses US White childhood cancer incidence in San Francisco to evaluate the hypothesis, the implications are widespread. The conclusions also relate to US Black children and all other persons. Living in the vicinity of the Sutro Tower in San Francisco significantly elevates the incidence of cancer. Other studies have found elevated adult and childhood cancers at residential RF/MW exposure levels in the United States (2-4), in Hawaii (5), in North Sydney, Australia (6), around 21 sites in the United Kingdom (7,8), and from the Vatican Radio Station in Rome (9).

There is consistent and comprehensive evidence requiring a revision of national RF/MW standards. Most standards are currently based on avoiding tissue heating. Public health protection standards for RF/MW exposures would be more appropriately based on multiple laboratory evidence of significant elevation and dose-response increases in genotoxicity and multiple studies showing significantly and dose-response elevated cancer rates from epidemiological evidence of RF/MW exposure.

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