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A post-Chernobyl rise in thyroid cancer in Connecticut, USA

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Recent analyses of children in Belarus and the Ukraine are the first to document large numbers of excess thyroid cancer cases only 4 years after exposure to radiation. In Connecticut (USA), a thyroid cancer increase of a much smaller magnitude occurred in 1990–93, 4–7 years after the Chernobyl accident, for both children and adults. Similar changes also occurred in the states of Iowa and Utah, which like Connecticut were exposed to low levels of radionuclides from Chernobyl fallout during May and June of 1986. Historical data from Connecticut also reveal substantial increases in thyroid cancer incidence about 5 years after large releases of iodine-131 from distant US nuclear weapons plants, after the largest atmospheric US atomic weapons tests in Nevada, and after substantial releases of iodine-131 from the Millstone nuclear power plant in Connecticut. Further analysis of this apparent 5-year latency period will enhance understanding of ionizing radiation's effects on thyroid function and on human health in general.

Key words: Chernobyl, iodine, radioactivity, thyroid cancer.

Introduction

Several recent reports have documented a dramatic increase in thyroid cancer in children under 15 living near Chernobyl following the nuclear accident on 26 April 1986. Beginning in 1990, sharp incidence rises occurred in the downwind Belarus region (Kazakov *et al*, 1992) and upwind Ukraine (Likhtarev *et al*, 1995). By 1991–94, the Belarus thyroid cancer rate had risen 100 times and the Ukrainian rate seven times from the levels in 1981–85. The number of cases in 1991–94 was 286 in Belarus and 149 in the Ukraine (Stsjakhko *et al*, 1995). Because pre-cancerous thyroid conditions in children are currently more common than carcinomas, health officials in the area expect future thyroid cancer rates to continue rising (Shapiro, 1995).

These reports represent the first instance that large excesses of thyroid cancer have been documented as early as 4 years after radiation exposure. A comparable latency may have occurred in Hiroshima/Nagasaki survivors, but no systematic study was performed until 1958–61, 13–16 years after the bombings, when 21 cases in a population of 15,000 were diagnosed (Socolow *et al*, 1963) In Rongelap, Marshall Islands, which received a large amount of fallout after a 1954 thermonuclear device test, the first case of thyroid cancer was not documented until 1965 (Conard *et al*, 1970). Six thyroid cancer cases (*vs* 1.4 expected) were found among Mormons living in southwest Utah in 1958–66, about 5 years after the 1951–62 US atmospheric bomb tests in nearby Nevada (Johnson, 1984). For Utah residents under 30, a total of 39 thyroid cancers (*vs* an expected 17) were detected from 1958 to 1962 (Weiss *et al*, 1967).

Average time between exposure to childhood therapeutic head and neck irradiation and diagnosis of thyroid carcinoma is about 25–35 years (Ron *et al*,

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1987; Schneider *et al*, 1993); one study showed only 12 of 309 (4%) of thyroid cancers developed within 10 years of exposure (Schneider *et al*, 1993). Recently, a link between a variety of X-rays and elevated thyroid cancer rates was identified, especially for papillary carcinoma, beginning with a latency of 5 years between exposure and diagnosis (Hallquist *et al*, 1994).

With a short latency for radiation-induced thyroid cancer near Chernobyl apparent, the question arises whether distant populations also experienced adverse effects. Fallout from Chernobyl travelled long distances, crossing the Atlantic Ocean and reaching the Americas. While levels of post-Chernobyl radionuclides in the US environment were much lower than those in Belarus and the Ukraine, few studies have yet been performed on any potential health effects of such small doses of these isotopes (Sperling *et al*, 1994).

Methodology

Thyroid cancer incidence for the state of Connecticut (USA) was selected for the study of post-Chernobyl effects. Connecticut, located 7200 km west of Chernobyl, has the oldest comprehensive tumour registry in the US, dating from 1935. The registry collects data from Connecticut hospital admitting records, hospital outpatient pathology/radiology records, death certificates and autopsies, and obtains information from physicians, hospitals and health departments in other states (Connecticut Department of Health Services, 1984). Due to the multiple sources of data and the age of the registry, cancer reporting is probably as complete in Connecticut as it is anywhere in the US.

Between 1960 and 1990, when it ceased such reporting, the US Environmental Protection Agency reported monthly levels of various radionuclides in milk in about 60 US cities; one of these elements is iodine-131, exposure to which poses a risk factor for thyroid cancer. The average level of ^{131}I in pasteurised milk in Hartford, Connecticut from 1983 to 1985 was about 0.02 Bq/l, but between 12 May and 2 June 1986, after Chernobyl fallout reached the US, six consecutive readings between 0.19 and 0.85 were recorded, as well as a level of 1.96 on 23 June, before the readings returned to customary levels (National Air and Radiation Environmental Laboratory, 1986). The May–June readings will correspond to changes in radioactivity ingested through the food chain, since no measures to restrict consumption were taken or suggested by American health officials. By July, most of the ^{131}I from Chernobyl had decayed and was no longer detectable, as the element has a physical half-life of 8.05 days (Table 1).

The May–June 1986 readings are higher than normal, but lower than the peak average of 2.59 Bq/l in September–October 1962, a time of heavy fallout from atmospheric weapons testing in Nevada. Except for late 1961 and 1962, only a few samples above 0.37 Bq were recorded during the 1960s and 1970s. Between 1960 and 1974, readings below 0.37 Bq/l were not specified, precluding any precise analysis of effects of ^{131}I during these years (US Public Health Service, 1960–1974).

Although exposure to radioactive iodine has been directly linked with thyroid cancer, it should be noted that there other radionuclides were also released from Chernobyl. These include isotopes that affect the cells in the bone marrow (and thus, the immune system),

Table 1. Becquerels per litre of iodine-131 and caesium-137 in pasteurized milk; Hartford, Connecticut, USA, 1983–90

Year	No. of readings	Average radioactivity (Bq/l)	
		I^{131}	Cs^{137}
1983	12	0.01	0.05
1984	12	0.00	0.08
1985	11	0.03	0.10
1986			
Jan–Apr	4	0.08	0.07
5 May–22 May	6	0.30	0.13
27 May–23 Jun	5	0.63	0.49
Jul–Dec	6	0.08	0.25
1987	12	0.10	0.23
1988	11	0.10	0.18
1989	11	0.09	0.08
1990	8	0.18	0.17

such as barium-140 (^{140}Ba), and others that disperse themselves throughout all tissues, such as caesium-137(^{137}Cs). The half-life of ^{140}Ba is 12.8 days, and that of ^{137}Cs is about 30 years. Levels of these two elements in Hartford's pasteurized milk rose sharply during May and June of 1986, due to Chernobyl fallout.

Table 1 also includes historical readings of ^{137}Cs in Hartford milk. Levels reached a record high of 5.55 Bq/l between June 1963 and May 1964, just after cessation of atmospheric nuclear weapons tests, and steadily declined thereafter. By the 1980s, levels were generally below 0.20 Bq/l, and even readings in May and June 1986 (0.13–0.49) were just a small fraction of those of the early 1960s (US Public Health Service, 1963–1964).

The post-Chernobyl iodine levels in the Connecticut milk supply signify an increase in the amount absorbed by the population, especially fetuses and infants. Normally, a nursing Connecticut infant's thyroid absorbs 7.3 mrad of ^{131}I per year, assuming the mother ingests 1 l of milk with 0.074 Bq of ^{131}I each day and that the infant absorbs 10 mrad for every 37 Bq of ^{131}I exposure. In 1986, the figure nearly doubled, reaching 13.5 mrad. For fetuses, assuming a thyroid gland 10% the size of an infant's during the last 180 days of gestation (Beierwaltes *et al*, 1960), the usual level of 36.0 mrad would have risen to 100.8 in 1986 (Committee on Food Protection, 1973). The figure of 100.8 mrad is more than double the 50 mrad of background radiation typically absorbed in 6 months.

Results

Table 2 presents age-adjusted thyroid cancer incidence for Connecticut residents from 1935–93, along with rates for individual age groups.

The data reveal a substantial increase between 1985–89 and 1990–93 in the state's age-adjusted incidence of 26.2% ($P < 0.0001$), following 10 years of virtually no change. Likewise, the rate rose for persons aged 0–19 (44%), 20–39 (27%; $P < 0.05$), 40–64 (23%; $P < 0.05$) and 65 or over (27%; $P < 0.05$). Incidence for persons aged 0–14 more than doubled, moving from 0.16 to 0.35; however, with only five and nine cases reported during these two periods, this increase has limited statistical significance ($P < 0.15$). While females account for nearly three-quarters of all thyroid cancer cases in the state, the increase for males (28%) was roughly equal to that for females (25%). Prior analysis has shown that much of the historical change involves papillary carcinoma, the type of thyroid cancer most affected by exposure to ionizing radiation (Pottern *et al*, 1980).

Connecticut's age-adjusted thyroid cancer incidence in the early 1990s was compared with those for two other American states with established tumour registries, Iowa and Utah. These states also received fallout from Chernobyl, perhaps in greater amounts than did Connecticut. The average level of ^{131}I in pasteurised milk in Des Moines, Iowa was 0.76 Bq/l for the period 20 May–25 June 1986 (seven readings, with a high of 1.37), compared with 0.03 Bq/l for the previous 6 months. ^{131}I samples in Salt Lake City,

Table 2. Thyroid cancer incidence rate per 100,000 adjusted to 1970 US standard and by age group; Connecticut, USA 1935–93

Year	All ages			0–14		0–19		20–39		40–64		65+	
	No.	Rate	% change	No.	Rate	No.	Rate	No.	Rate	No.	Rate	No.	Rate
1935–39	58	0.79	–	0	0.00	4	0.15	2	0.07	27	1.14	25	4.23
1940–44	79	0.94	18.2	0	0.00	1	0.04	6	0.20	42	1.58	30	4.20
1945–49	109	1.09	15.8	1	0.05	1	0.04	25	0.80	47	1.66	36	4.39
1950–54	227	2.02	86.0	1	0.04	2	0.06	55	1.70	105	3.42	65	5.79
1955–59	253	2.04	0.9	2	0.06	7	0.17	68	2.08	111	3.23	67	5.96
1960–64	324	2.45	19.9	5	0.13	16	0.33	99	2.94	117	3.13	92	7.29
1965–69	402	2.75	12.4	4	0.10	11	0.20	131	3.57	168	4.13	92	6.69
1970–74	468	2.97	8.0	3	0.07	19	0.35	146	3.65	196	4.60	107	7.07
1975–79	567	3.43	15.3	8	0.23	27	0.54	198	4.41	237	5.64	105	6.20
1980–84	620	3.46	0.9	8	0.25	17	0.38	216	4.24	260	6.19	127	6.66
1985–89	642	3.45	−0.2	5	0.16	19	0.44	196	3.58	278	6.43	149	7.04
1990–93[a]	666	4.35	26.2	9	0.35	21	0.63	195	4.55	287	7.88	163	8.98

[a] 4 years.

Table 3. Age-adjusted thyroid cancer incidence rate per 100,000 adjusted to 1970 US Standard; Connecticut, Iowa and Utah, 1985–89 to 1990–93

State	No. of cases		Rate		
	1985–89	1990–93[a]	1985–89	1990–93[a]	% change
Utah	412	393	5.36	6.07	13.1*
Iowa	684	640	4.32	5.14	18.8**
Connecticut	642	666	3.45	4.35	26.2†
Total	1738	1699	4.13	4.93	19.4†

*$P < 0.10$.
**$P < 0.01$.
†$P < 0.0001$.
[a] 4 years.

Utah averaged 1.03 Bq/l from 13 May to 26 June 1986 (11 readings, with a high of 2.37) *vs* an average of zero for the 6 months prior to Chernobyl. Table 3 displays the change in thyroid cancer incidence for Connecticut, Iowa and Utah from 1985–89 to 1990–93.

Rates in each of the states advanced during 1990–93, and increases were statistically significant for Connecticut and Iowa. Increases in the early 1990s exceeded the average 5-year change for the previous 10 years in Iowa (18.8% *vs* 13.5%), Utah (13.1% *vs* 5.5%), and Connecticut (26.2% *vs* 0.3%). Only a minority of the 50 US states maintain historical data on cancer incidence; the incidences in these three states account for about 3.5% of the 50,000 thyroid cancer cases estimated to occur in the US in the period 1990–93 (Ries *et al*, 1987-1990).

Discussion

Thyroid cancer data for children in Connecticut indicate that an increase occurred, beginning 4 years after the Chernobyl accident, even though the number of cases is relatively few. This result is similar to that found in children in Belarus and Ukraine, although the change is much smaller. Increases were also documented for all age groups in Connecticut, as well as in the states of Iowa and Utah. Although elevated levels of ^{131}I and other radionuclides were observed in the US during May and June of 1986 due to Chernobyl fallout, the levels are still relatively low, and certainly much lower than in the areas closest to Chernobyl. The documentation of a short latency between radiation exposure and thyroid cancer diagnosis in children in Belarus and Ukraine, and the suggestion that this may have also occurred in areas of low-level exposure present a broader issue to be considered. It will be intriguing to examine further any connection between cancer and protracted low-level exposures from Chernobyl fallout.

Diagnostic criteria for thyroid cancer in the US have not changed between the late 1980s and early 1990s. US medical personnel took no additional measures to detect thyroid abnormalities after Chernobyl (in contrast to the former Soviet Union, which instituted clinics and screening programmes in affected areas). Hence, the increase in cancer several years after the accident appears to be a true one. This finding coincides with conclusions of previous studies of rising thyroid cancer in Connecticut, which determined that better reporting alone cannot explain such a trend (Clark *et al*, 1955; Ron *et al*, 1987).

Historical data from Connecticut in Table 2 also reveal that there are three periods (in addition to the early 1990s, already discussed) which show the greatest absolute and percentage changes in thyroid cancer incidence:

1. 1945–49 to 1950–54: from 1.09 to 2.02, increase of 0.93 (86.0%).
2. 1955–59 to 1960–64: from 2.04 to 2.45, increase of 0.41 (19.9%).
3. 1970–74 to 1975–79: from 2.97 to 3.43, increase of 0.46 (15.3%).

The period 1950–54 represents about 5 years after the start of the US nuclear weapons programme. Prior to the Hiroshima and Nagasaki bombs, the first nuclear device was exploded near Alamogordo, New Mexico on 16 July 1945. To manufacture these three bombs, the two initial nuclear weapons plants emitted large amounts of ^{131}I into the atmosphere. From 1944 to 1947, the plant at Hanford, Washington state, emitted 25.3×10^{15} Bq of ^{131}I, compared with 2.0×10^{15} Bq over the subsequent 25 years (Hanford Health Information Network, 1994). At Oak Ridge, Tennessee, exact amounts of ^{131}I emissions are unknown, but because the stacks at the plant were unfiltered from 1943 to 1948, releases were large. For example, 2.4×10^{15} Bq of ^{131}I were released from the Oak Ridge National Laboratory in 1947 (Tennessee Department of Health, 1993).

The period 1960–64 is about 5 years after the US atmospheric weapons tests in Nevada yielding the greatest kilotonnage. The 1957 test series had the highest yield (346 kilotons); this series followed those in 1955 (167 kt) and 1953 (252 kt). These 3 years account for about 85% of all yields from atmospheric testing in Nevada from 1951–62. In addition, US atmospheric detonations in the Pacific during 1954–56 and 1956–58 produced a yield of 103,000 kt, about 80% of the total output from Pacific tests from 1946 to 1962 (Norris and Cochran, 1994). Fallout from these tests (especially those in Nevada) drifted eastward across the continental US, carried by prevailing winds, and entered the environments of many states (including Connecticut), often through precipitation. Introduction of fallout particles into the food chain caused Americans to ingest radioactive products, including iodine. Although records were only kept in nine US cities (none in Connecticut) in the late 1950s, ^{131}I levels in New York City (160 km southwest of Connecticut) averaged as much as 8.02 Bq/l in raw milk, from September to November 1957. Children born in New York City in 1957 were estimated to have absorbed a dose of about 620 mrad of ^{131}I to their thyroid gland by 1963, slightly more than the 600 mrad absorbed through background radiation. Amounts for children in other US cities such as St Louis and Salt Lake City were nearly three times as much as those in New York City (US Public Health Service, 1963, 1969).

The period 1975–79 is approximately 5 years after the opening of the Millstone nuclear power plant in Waterford, Connecticut, which emitted relatively large amounts of fission products into the atmosphere during its first years. Millstone began operations in 1970, and released 1.15×10^{12} Bq of ^{131}I from 1970 to 1979, compared with 5.42×10^{10} Bq from 1980 to 1986. The greatest annual release (3.69×10^{11} Bq) occurred in 1975 (Nuclear Regulatory Commission, 1970–1986). Table 4 presents historical data from

Table 4. Thyroid cancer cases, all ages and sexes; Middlesex and New London counties, Connecticut, USA, 1950–93

Year	No. of cases in county	Crude rate: County		Crude rate: Rest of state	
Middlesex county					
1950–52[a]	4	1.92	(–)	2.15	(–)
1953–57	9	2.30	(+19.8%)	1.92	(–10.7%)
1958–62	10	2.25	(–2.2%)	2.40	(+25.0%)
1963–67	13	2.55	(+13.3%)	2.46	(+2.5%)
(Haddam Neck reactor start-up)					
1968–72	14	2.44	(–4.3%)	2.86	(+16.3%)
1973–77	23	3.77	(+54.7%)	3.38	(+18.2%)
1978–82	23	3.57	(–5.3%)	3.47	(+2.7%)
1983–87	30	4.41	(+23.5%)	4.20	(+21.0%)
1988–92	26	3.63	(–17.7%)	4.61	(+9.8%)
New London county					
1951–55	15	1.91	(–)	2.06	(–)
1956–60	14	1.57	(–17.8%)	1.97	(–4.4%)
1961–65	17	1.71	(+8.9%)	2.39	(+21.3%)
1966–70	17	1.54	(–9.9%)	2.75	(+15.0%)
(Millstone reactor start-up)					
1971–75	20	1.72	(+11.7%)	3.04	(+10.5%)
1976–80	38	3.21	(+86.8%)*	3.41	(+12.2%)
1981–85	42	3.45	(+7.4%)	4.04	(+18.5%)
1986–90	62	4.93	(+42.9%)	4.24	(+5.0%)
1991–93[a]	51	6.69	(+35.7%)	4.98	(+17.5%)

*$P < 0.05$.
[a] 3 years.

Millstone's home county (New London), as well as Middlesex county (the location of Haddam Neck, Connecticut's other nuclear power plant).

In the period 1976–80, 5 years after Millstone's early operations, the number of thyroid cancer cases in New London county jumped from 20 to 38, an increase in the crude rate of 86.8% (compared with 12.2% for the other seven Connecticut counties). In Middlesex county, the number increased from 14 to 23 (crude rate increase of 54.7%, *vs* 18.2% elsewhere in the state) 5 years after Haddam Neck opened in 1967. Releases from Haddam Neck were considerably lower than at Millstone. Because only crude rates are available, these increases are imprecise. However, it is clear that age-adjusted rates also rose substantially, beginning 5 years after the two Connecticut reactors initiated operations, in these two counties.

Thyroid cancer incidence has risen in Connecticut in all but one 5-year period since the 1930s, at an average annual rate of about 3%. Thus, some increase in the early 1990s can be expected, with or without introduction of iodine from a nuclear accident into the environment. However, the upswing after 1989 follows 10 years of unchanged rates marked by falling incidence for the population under age 40; the proportion of this group that received head and neck irradiation in childhood, a practice associated with thyroid cancer risk that ceased by the late 1950s, is dropping. After 1989, however, rates increased for all age groups, including the under-40 population. Thus, the pattern in the early 1990s can be seen as a departure from the trend expected from the previous 10 years.

Perhaps the most revealing finding of this study is that exposure to relatively low levels of radioactivity may add to cancer risk after just a few years. Children in Belarus and the Ukraine received several hundred rads, or thousands of times the level of iodine than their Connecticut counterparts (Anspaugh *et al*, 1988). However, thyroid cancer increases for children since the late 1980s in Belarus (665%) and the Ukraine (209%) are not thousands of times greater than that of Connecticut children (117%) (Stsjakhko *et al*, 1995). It is possible that effects on thyroid function from low levels of iodine are greater than previously believed, and may resemble the supralinear dose response found by other researchers (Petkau, 1972; Gould and Sternglass, 1989). Future studies on changes in thyroid cancer and other diseases should assess the dose-response relationship for various levels of Chernobyl fallout.

The full health legacy of the Chernobyl disaster will not be known for many years. However, the first adverse health effect, increased thyroid cancer in local children beginning 4 years after the accident, has been documented. This paper suggests a statistical link between exposure to Chernobyl fallout and elevated thyroid cancer rates in distant populations exposed to lower levels of iodine and other radionuclides; this link includes both children and adults. Future study on thyroid cancer patterns will greatly aid the understanding of Chernobyl's effects, as well as the effects of protracted, low level radiation exposures on human health.

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