AN UNEXPECTED MORTALITY INCREASE IN THE UNITED STATES FOLLOWS ARRIVAL OF THE RADIOACTIVE PLUME FROM FUKUSHIMA: IS THERE A CORRELATION?

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The multiple nuclear meltdowns at the Fukushima plants beginning on March 11, 2011, are releasing large amounts of airborne radioactivity that has spread throughout Japan and to other nations; thus, studies of contamination and health hazards are merited. In the United States, Fukushima fallout arrived just six days after the earthquake, tsunami, and meltdowns. Some samples of radioactivity in precipitation, air, water, and milk, taken by the U.S. government, showed levels hundreds of times above normal; however, the small number of samples prohibits any credible analysis of temporal trends and spatial comparisons. U.S. health officials report weekly deaths by age in 122 cities, about 25 to 35 percent of the national total. Deaths rose 4.46 percent from 2010 to 2011 in the 14 weeks after the arrival of Japanese fallout, compared with a 2.34 percent increase in the prior 14 weeks. The number of infant deaths after Fukushima rose 1.80 percent, compared with a previous 8.37 percent decrease. Projecting these figures for the entire United States yields 13,983 total deaths and 822 infant deaths in excess of the expected. These preliminary data need to be followed up, especially in the light of similar preliminary U.S. mortality findings for the four months after Chernobyl fallout arrived in 1986, which approximated final figures.

We recently reported on an unusual rise in infant deaths in the northwestern United States for the 10-week period following the arrival of the airborne radioactive plume from the meltdowns at the Fukushima plants in northern Japan. This result suggested that radiation from Japan may have harmed Americans, thus meriting more research. We noted in the report that the results were

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preliminary, and the importance of updating the analysis as more health status data become available (1).

Shortly after the report was issued, officials from British Columbia, Canada, proximate to the northwestern United States, announced that 21 residents had died of sudden infant death syndrome (SIDS) in the first half of 2011, compared with 16 SIDS deaths in all of the prior year. Moreover, the number of deaths from SIDS rose from 1 to 10 in the months of March, April, May, and June 2011, after Fukushima fallout arrived, compared with the same period in 2010 (2). While officials could not offer any explanation for the abrupt increase, it coincides with our findings in the Pacific Northwest.

Any comparison of potential effects of radiation exposure must attempt to examine the dose-response relationship of the exposure of a population. In the United States, the principal source of dose data (i.e., environmental radiation levels) is the U.S. Environmental Protection Agency (EPA). Health data are the responsibility of the U.S. Centers for Disease Control and Prevention (CDC), which provides weekly reports on mortality in 122 U.S. cities. These are preliminary data, but are the most useful at a date so soon after an event such as Fukushima.

The goal of this report is to evaluate any potential changes in U.S. mortality resulting from exposure to the Fukushima plume, using EPA and CDC data.

BACKGROUND: POST-CHERNOBYL HEALTH TRENDS

A quarter of a century before the Fukushima disasters, the meltdown at Chernobyl and the presence of environmental fallout presented a similar challenge for researchers to assess any adverse health effects. The discussion that began after the April 26, 1986, meltdown is still very much a current one, with varying estimates. A recent conference concluded that 9,000 persons worldwide survived with or died from cancer (3), while a compendium of more than 5,000 research papers put the excess death toll (from cancer and all other causes) at 985,000 (4).

In the United States, Chernobyl fallout was detected in the environment just nine days after the meltdown. Gould and Sternglass (5) used EPA measurements of environmental radiation post-Chernobyl (6) and found elevated levels of radioactivity in air, water, and milk. For example, EPA data indicate that from May 13 to June 23, 1986, U.S. milk had 5.6 and 3.6 times more iodine-131 and cesium-137 than were recorded in May–June of 1985 (see Appendix Table 1, p. 60). In some cities, especially those in the harder-hit Pacific Northwest, average concentrations were as much as 28 times the norms, while some individual samples were much higher.

Gould and Sternglass (5) also studied preliminary mortality data, to analyze any potential impact from fallout. Using a 10 percent sample of all U.S. death certificates, they found that during the four months after Chernobyl (May–August

1986), total deaths in the United States rose 6.0 percent over the similar period in 1985 (see Appendix Table 2) (7; estimated deaths based on a 10% sample of death certificates, minus the New England states, for which data were incomplete at the time).

Eventually, final figures showed an increase of 2.3 percent, which exceeded the 0.2 percent decline in the first four months of the year (8). The number of excess deaths, or the difference between the actual and expected death totals, is 16,573. To date, the cause of this unusual pattern remains unknown, and no research testing hypotheses for causes other than Chernobyl has been published. This difference has a very high degree of statistical significance; there is a less than 1 in 10^9 probability that it occurred by random chance.

The change in deaths for infants was also analyzed. Preliminary data showed an increase of 3.1 percent in U.S. infant deaths in the first four months after Chernobyl, 1985 versus 1986. The final increase was 0.1 percent, compared with a 2.3 percent decline in the four months before Chernobyl. The 1985–1986 differences in infant death rates were –2.9 percent (January–April) and +0.4 percent (May–August). These gaps amounted to excess infant deaths of 306 and 424, and differences were significant at $p < 0.08$ and $p < 0.055$.

The stillbirth, neonatal, and prenatal mortality increased in England and Wales within 11 months after Chernobyl's initial release (9, 10), and in Germany (11). In two Ukrainian districts with increased levels of cesium-137 ground contamination, there was a significant increase in stillbirths (12).

U.S. publications offered evidence that Americans may have suffered harm from Chernobyl, especially damage to fetuses and infants. Reports covered elevated levels of various radiation-related disorders, including newborn hypothyroidism (13), infant leukemia (14), and thyroid cancer among children (15).

Gould and Sternglass (5) showed that trends using preliminary data were rough approximations of the final data. Because of the lengthy delay in generating final statistics—2011 data will probably not be published on the CDC website until 2014—we believe that analyzing preliminary health data at this time is a useful exercise that can approximate final mortality patterns and help guide future research on the effects of fallout from the Fukushima meltdowns.

METHODS

Environmental Radioactivity

The first component of any analysis of potential adverse health effects from Fukushima fallout in the United States is the doses received by humans. After March 17, 2011, when the airborne radioactive plume first reached the United States, the EPA accelerated its program of sampling environmental radioactivity. Instead of quarterly measures in precipitation, milk, water, and air, samples were taken weekly, sometimes more frequently. Radioisotope levels in late March and early April tended to be higher than typical levels, but declined in April, even though Fukushima meltdowns and emissions continued. On May 3, the EPA announced that it would revert to quarterly measurements.

The number of samples and percentage with detectable radioisotope levels reported by the EPA in March–April 2011 were far fewer than those taken and reported in the period after Chernobyl in May–June 1986. Reporting for some of the principal radioisotopes is given in Table 1 (16).

The number of samples for which the EPA was able to detect measurable concentrations of radioactivity is relatively few. Assuming that the EPA attempted to measure each of the 10 isotopes in air, precipitation, milk, and drinking water, only 13.3, 6.2, 2.2, and 2.4 percent, respectively, resulted in detectable levels. Of the 452 samples with detectable levels, 297 were iodine-131 measurements.

This dataset was much weaker than that reported by the EPA in May–June 1986, in the aftermath of the Chernobyl meltdown. For example, the EPA reported 2,304 milk samples in the United States, with 2,000 (86.8%) reporting a positive number for the three isotopes barium-140, cesium-137, and iodine-131 (6). After Fukushima, there were 670 measurements of milk for 10 isotopes, with just 2.2 percent reporting a positive numerical value (16). Clearly, the 2011 EPA reports cannot be used with confidence for any comprehensive assessment of temporal trends and spatial patterns of U.S. environmental radiation levels originating in Japan.

Table 1

Concentrations of radioisotopes in the environment, United States: 10 isotopes measured by the EPA, March and April 2011 (after Fukushima)

	Number (%) of samples with detectable levels reported			
	Air (n = 229)	Precipitation (n = 157)	Milk (n = 67)	Drinking water (n = 153)
Barium-140	4.4 (10)	0.0 (0)	0.0 (0)	0.0 (0)
Cesium-134	14.8 (34)	5.7 (9)	3.0 (2)	0.7 (1)
Cesium-136	2.2 (5)	0.0 (0)	0.0 (0)	0.0 (0)
Cesium-137	20.1 (46)	7.0 (11)	6.0 (4)	0.7 (1)
Cobalt-60	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Iodine-131	77.3 (177)	49.0 (77)	13.4 (9)	22.2 (34)
Iodine-132	13.1 (30)	0.0 (0)	0.0 (0)	0.0 (0)
Iodine-133	0.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)
Tellurium-129	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Tellurium-129m	0.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)
Total all	13.3 (304)	6.2 (97)	2.2 (15)	2.4 (36)
Total excluding I-131	6.2 (127)	1.4 (20)	1.0 (6)	0.1 (2)

Source: U.S. Environmental Protection Agency (16).

The EPA data cannot be used to assess the amount of time that Fukushima radiation existed in the U.S. environment, or which areas of the nation received the highest amount of fallout. Anecdotal samples provide an abridged set of data. For example, iodine-131 in precipitation reached 242 and 390 picocuries per liter (pCi/L) in Boise, Idaho, on March 22, hundreds of times greater than the typical value of about 2.0 pCi/L. The next highest value (200 pCi/L) was recorded in Kansas City, Kansas, on March 29. The 10 highest values included diverse locations such as Salt Lake City, Utah (190 pCi/L), Jacksonville, Florida (150 pCi/L), and Boston, Massachusetts (92 pCi/L). Despite the paucity of data, it appears that radioactivity from Fukushima reached many, perhaps all, areas of the United States. Without more specific data, only the United States as a whole can be used to understand any potential changes in health status.

Health Status

Vital statistics in the United States, including morbidity and mortality, are typically not made publicly available until at least two years after the event occurred. Moreover, vital statistics are publicly issued only for entire years, not portions of years, as would be needed to analyze temporal trends before and after the Fukushima meltdowns. Obtaining data for portions of years would be possible only by making special requests to state and local health departments that maintain and collect data.

The CDC produces weekly statistics on U.S. deaths for each of five age groups and for all ages combined, and for pneumonia/influenza, as part of the *Morbidity and Mortality Weekly Report*. The statistics include 122 U.S. cities with populations over 100,000, representing about 25 to 35 percent of the nation's deaths. The number of deaths is reported voluntarily by health officers in these cities, and represents the place of occurrence of death rather than the place of residence. A death is counted when the death certificate is filed, not necessarily on the date of death. Only raw numbers of deaths, and not mortality rates, are given. In some cities, a week's total is reported with a "U" (unavailable), although by 2011 this lack of reported information occurred only in a small minority of participating cities.

While the limitations of the CDC weekly mortality statistics should be understood and considered, so that the data are cautiously interpreted, these limits should not preclude their use. Each week, about 11,000 total deaths are reported. The experience of mortality patterns found by Gould and Sternglass (5) using a 10 percent sample of U.S. deaths that approximated final statistics offers further evidence that the CDC mortality data can be helpful at this still-early date.

In this report, we analyze changes in U.S. deaths in the period after Fukushima fallout arrived in North America, compared with a similar period for 2010. Total deaths and deaths of infants under one year, who are most susceptible to the adverse health effects of exposure to radioactivity, are reported.

As of this writing, 14 weeks of post-Fukushima data have been reported by the CDC. All but 3 of the 122 cities in the CDC report submitted actual number of deaths (vs. "unavailable") in more than 99 percent of the reporting periods. This 14-week period includes weeks 12 to 25 of 2011 (March 20 to June 25), approaching the four-month period in which Gould and Sternglass found an unexpectedly large increase in deaths after Chernobyl. Here, reported deaths are compared with weeks 12 to 25 in 2010 (March 21 to June 26). Any 2010–2011 changes are compared with those for the prior 14-week period (December 12, 2009, to March 20, 2010 vs. December 11, 2010, to March 19, 2011: weeks 50 to 52 and 1 to 11).

The 2010–2011 comparison of deaths in weeks 12 to 25 included 119 of the 122 cities in the CDC report. Excluded were Fort Worth, Texas; New Orleans, Louisiana; and Phoenix, Arizona; for these cities, deaths in more than half of the weeks were reported as "unavailable." The completeness of reporting for both periods exceeded 99 percent. For the earlier 14-week periods, only 104 of the 122 cities that reported death figures more than 99 percent of the time were included. For the cities and weeks excluded from the analysis, see Appendix Table 3.

Statistical significance between the 2010 and 2011 death trends was calculated by using the difference between two means. The observed difference was the actual 2010–2011 change for weeks 12 to 25, and the expected difference was the 2010–2011 change for the preceding 14 weeks. The formula used for calculating statistical significance is given in Appendix Table 4.

RESULTS

U.S. Total Deaths

During weeks 12 to 25, total deaths in 119 U.S. cities increased from 148,395 (2010) to 155,015 (2011), or 4.46 percent. This was nearly double the 2.34 percent rise in total deaths (142,006 to 145,324) in 104 cities for the prior 14 weeks, significant at $p < 0.000001$ (Table 2). This difference between actual and expected changes of +2.12 percentage points (+4.46% – 2.34%) translates to 3,286 "excess" deaths (155,015 × 0.0212) nationwide. Assuming a total of 2,450,000 U.S. deaths will occur in 2011 (47,115 per week), then 23.5 percent of deaths are reported (155,015/14 = 11,073, or 23.5% of 47,115). Dividing 3,286 by 23.5 percent yields a projected 13,983 excess U.S. deaths in weeks 12 to 25 of 2011.

After March 19, 2011, total deaths were higher than a year earlier in 11 of the 14 weeks, with a 7.5 percent or greater increase in four of the weeks. The greatest rise occurred in weeks 12 to 20, with a 5.37 percent increase (96,900 to 102,108). In weeks 21 to 25, the increase was a considerably lower 2.74 percent (51,495 to 52,907). Whether this pattern will continue into the future or is temporary is not yet known.

Table 2

Changes in reported deaths, all ages: weeks 12 to 25 and 14 weeks prior, 2010 versus 2011, 122 U.S. cities

	Total deaths				Total deaths		
Week	2010	2011	No. (%) change	Week	2010	2011	No. (%) change
12	11,010	12,137	+1,127 (+10.24)	50	10,323	10,702	+379 (+3.67)
13	11,097	11,739	+642 (+5.79)	51	7,942	8,339	+397 (+5.00)
14	11,075	12,052	+977 (+8.82)	52	8,288	8,194	−94 (−1.13)
15	10,712	10,928	+216 (+2.02)	1	11,557	11,804	+247 (+2.14)
16	10.940	10,743	−197 (−1.80)	2	11,299	10,775	−524 (−4.64)
17	10,549	10,826	+277 (+2.63)	3	10,110	10,689	+579 (+5.73)
18	10,637	11,251	+614 (+5.77)	4	10,832	10,420	−412 (−3.80)
19	10,389	11,300	+911 (+8.77)	5	10,524	10,295	−229 (−2.18)
20	10,491	11,132	+641 (+6.11)	6	9,877	10,700	+823 (+8.33)
21	10,352	10,839	+487 (+2.77)	7	9,802	10,952	+1,150 (+11.73)
22	9,894	9,538	−356 (−3.60)	8	10,198	10,762	+564 (+5.53)
23	10,781	10,770	−11 (−0.10)	9	10,586	10,779	+193 (+1.82)
24	10,178	10,981	+803 (+7.89)	10	10,699	10,639	−60 (−0.56)
25	10,290	10,779	+489 (+4.75)	11	9,969	10,274	+305 (+3.06)
Total	148,395	155,015	+6,620 (+4.46)*	Total	142,006	145,324	+3,318 (+2.34)

Note: For weeks 12 to 25, actual numbers of deaths were available for 1,653 (99.22%) in 2010 and 1,650 (99.04%) in 2011 of the 119 cities for the 14 weeks. For weeks 50 to 52 and 1 to 11, actual numbers of deaths were available for 1,445 (99.24%) in 2010 and 1,443 (99.11%) in 2011 of the 104 cities for the 14 weeks.

*$p < 0.000001$

U.S. Infant Deaths

The CDC weekly report provides reported deaths in the 122 participating cities for each of five age groups (<1, 1–24, 25–44, 45–64, and over 65). Of special interest to any analysis of potential health risks of environmental toxins are the fetus and infant, which are at greater risk than older children or adults. Their immune systems are immature and less likely to fight off disease; their cells are dividing very rapidly and are less likely than a damaged adult cell to repair before mitosis. Thus, we examined trends for deaths of infants under one year old. The same cities used for total deaths are used here (Table 3). Infant death numbers are much smaller, accounting for just over 1 percent of total U.S. deaths in recent years.

Between 2010 and 2011, the total number of infant deaths for weeks 12 to 25 rose 1.80 percent (2,674 to 2,722), compared with a 8.37 percent decline (2,520 to 2,309) in the prior 14-week period. This difference was highly significant ($p < 0.0002$). In 8 of 14 weeks after March 19, 2011, an increase occurred from the year before, compared with just 4 of 14 weeks in the prior 14-week period. Some weeks had relatively large increases and decreases, because the smaller number of infant deaths is subject to greater variability.

The 10.17 percentage point difference between actual and expected (+1.80% and –8.37%) means that 277 of the 2,722 infant deaths (2,772 × 0.1017) are "excess." Assuming that 30,000 U.S. infant deaths will occur in 2011 (577 per week), this means that 33.7 percent of deaths are reported (2,722/14 = 194, or 33.7% of 577). Dividing 277 by 33.7 percent yields a projected 822 excess infant deaths in the United States in the 14 weeks after March 19, 2011.

Individual Locations

Another means of analyzing trends in mortality is to study geographic area. The CDC weekly report can be subdivided into either individual cities or regions. It is difficult to offer an a priori hypothesis on areas with the highest expected mortality increases after Fukushima fallout arrived, since the EPA data on radioactivity levels are limited. Moreover, voluntary reporting practices in a single city or area are subject to change over time, potentially skewing trends. The impact of such changes is less likely to affect patterns in a national group of 122 cities, since it is more likely that changes that increase or decrease deaths would offset each other.

Deaths reported from U.S. cities with the largest populations and complete reporting in weeks 12 to 25 (2010 and 2011) and from the 14 previous week periods are given in Table 4 (all deaths) and Table 5 (infant deaths). Of the eight most populated cities, Chicago and Phoenix (3rd and 5th highest population) are omitted due to incomplete data.

Table 3

Changes in reported infant deaths, age under one year old: weeks 12 to 25 and 14 weeks prior, 2010 versus 2011, 122 U.S. cities

	Infant deaths				Infant deaths		
Week	2010	2011	No. (%) change	Week	2010	2011	No. (%) change
12	202	201	−1 (−0.50)	50	177	202	+25 (+14.12)
13	182	210	+28 (+15.38)	51	150	129	−21 (−14.00)
14	189	198	+9 (+4.76)	52	120	113	−7 (−5.83)
15	208	163	−45 (−21.63)	1	198	158	−40 (−20.20)
16	186	188	+2 (+1.08)	2	193	177	−16 (−8.29)
17	177	200	+23 (+12.99)	3	206	158	−48 (−23.30)
18	200	196	−4 (−2.00)	4	207	148	−59 (−28.50)
19	172	214	+42 (+24.42)	5	177	178	+1 (+0.56)
20	221	224	+3 (+1.36)	6	174	173	−1 (−0.57)
21	183	196	+13 (+7.10)	7	165	188	+23 (+13.94)
22	173	152	−21 (−12.14)	8	191	158	−33 (−17.27)
23	205	174	−31 (−15.12)	9	192	174	−18 (−9.38)
24	194	191	−3 (−1.55)	10	189	165	−24 (−12.70)
25	182	215	+33 (+18.13)	11	181	188	+7 (+3.87)
Total	2,674	2,722	+48 (+1.80)*	Total	2,520	2,309	−211 (−8.37)

Note: For weeks 12 to 25, actual numbers of deaths were available for 1,653 (99.22%) in 2010 and 1,650 (99.04%) in 2011 of the 119 cities for the 14 weeks. For weeks 50 to 52 and 1 to 11, actual numbers of deaths were available for 1,445 (99.24%) in 2010 and 1,443 (99.11%) in 2011 of the 104 cities for the 14 weeks.

*$p < 0.0002$

Table 4

Changes in reported deaths, all ages: weeks 12 to 25, 2010 versus 2011 (vs. 14 weeks prior), most populated U.S. cities

City (population rank)	Total deaths 2010	Total deaths 2011	No. (%) change, 2010–2011 Weeks 12–25		Prior 14 weeks	
1. New York City	13,697	13,779	+82	(+0.60)	+1038	(+6.99)
2. Los Angeles	3,440	3,686	+246	(+7.15)	+44	(+1.17)
4. Houston	2,291	2,775	+484	(+21.13)	−1.649	(−45.03)
6. Philadelphia	3,708	4,044	+336	(+9.06)	+207	(+5.42)
7. San Antonio	3,489	3,511	+22	(+0.63)	+222	(+6.32)
8. San Diego	2,357	2,220	−137	(−5.81)	+199	(+9.74)
Total	28,982	30.015	+1,033	(+3.56)	+61	(+0.19)

Note: Deaths reported for all weeks and cities except San Antonio (week ending 12/26/2009) and San Diego (week ending 12/19/2009).

Table 5

Changes in reported deaths, age under one year old: weeks 12 to 25, 2010 versus 2011 (vs. 14 weeks prior), most populated U.S. cities

City (population rank)	Total deaths 2010	Total deaths 2011	No. (%) change, 2010–2011 Weeks 12–25		Prior 14 weeks	
1. New York City	164	163	−1	(−0.61)	+32	(+20.92)
2. Los Angeles	74	58	−16	(−21.62)	−11	(−14.29)
4. Houston	105	117	+12	(+11.43)	−19	(−18.63)
6. Philadelphia	79	93	+14	(+17.22)	−7	(−7.14)
7. San Antonio	60	40	−20	(−33.33)	−8	(−14.29)
8. San Diego	37	33	−4	(−10.81)	+5	(+11.11)
Total	519	504	−15	(−2.89)	−8	(−1.51)

Note: Deaths reported for all weeks and cities except San Antonio (week ending 12/26/2009) and San Diego (week ending 12/19/2009).

For deaths of all ages, the U.S. 2010–2011 change of +3.56 percent in the 14 weeks after mid-March was well above the +0.19 percent change for the 14-week period before mid-March. This difference between the two changes of +3.37 percentage points was statistically significant at $p < 0.0001$.

DISCUSSION

The Fukushima meltdowns, and the introduction of radioactivity across the globe, indicate that accurate measurements are needed on subsequent changes in environmental radioactivity and in health status. In the United States, there have been limitations in both measures. Radioactivity samples in precipitation, air, water, and milk were sporadically reported by the Environmental Protection Agency. Many measurements failed to produce detectable levels, and on May 3, 2011, the agency reverted to its policy of making only quarterly measurements. Some elevated concentrations were found to be up to several hundred times the norm soon after the arrival of the Fukushima fallout, but no meaningful temporal trends and spatial patterns can be discerned from these data.

Few aggregate data on health status are available until several years after a death or specific diagnosis. Immediately after Fukushima, the only nationwide health status data available in the United States were weekly deaths by age reported by 122 U.S. cities (about 25% to 35% of all U.S. deaths), as reported by the Centers for Disease Control and Prevention. In the 14 weeks after the Fukushima fallout arrived in the United States, total deaths reported were 4.46 percent above the same period in 2010; in the 14 weeks before Fukushima, the increase from the prior year was just 2.34 percent. The gap in changes for infant deaths (+1.80% in the latter 14 weeks, –8.37% for the earlier 14 weeks) was even larger. Estimated "excess" deaths for the entire United States were projected to be 13,983 total deaths and 822 infant deaths.

Patterns of deaths among persons of all ages strongly reflect patterns among the elderly, who account for over two-thirds of all deaths. For the older population, explanations for excess deaths must be considered after exposure to higher levels of radioactive fallout. If cancer in some patients becomes active again, it may mean they already have cells carrying all but one of the three to four requisite mutations to express cancer. Exposure to radiation (or a toxic chemical) can provide the one final mutation to reactivate a quiescent tumor (17). Also vulnerable are those elderly with depressed immune status, made worse by exposure to radiation.

The CDC weekly mortality data have limitations. They represent only a 25 to 35 percent sample of all deaths, which may or may not accurately represent the entire nation. Deaths are reported voluntarily and thus are subject to variations from city to city and for unusual circumstances in a week or period (e.g., totals during the Christmas holiday season appear to be much lower). Weekly totals are sometimes reported as unavailable and so cannot be used in any analysis. The deaths reported are by city of occurrence, whereas all final statistics are by residence at time of death. Deaths are categorized when the death certificate is filed, not necessarily the date of death. Finally, the CDC weekly reports provide raw numbers of deaths, not the more useful mortality rates, as populations or numbers of births are not given.

Nonetheless, 25 to 35 percent of the United States is not a small sample, representing all large cities and many smaller ones in all regions of the nation. When extended periods are used, the numbers become larger and more meaningful, because any variations increasing or decreasing death counts are more likely to balance each other out. The total of 155,015 U.S. deaths in the 14-week period after Fukushima, 2,722 of which are infant deaths, represents a large database that is meaningful in a preliminary analysis of potential Fukushima effects. Not to use them would mean a two- or three-year absence of any health status data, until final figures are made public.

The statistically significant difference in increased number of reported deaths (total and infant) for the 14-week period after Fukushima has an added dimension because of similar findings for the four months immediately after the Chernobyl meltdown in 1986, using a 10 percent sample of U.S. deaths. The post-Chernobyl increases, based on preliminary death data, were roughly comparable to the increases calculated from final death data (see Appendix Table 2). The preliminary versus final 1985–1986 change for the period May–August in total deaths was within 3.7 percentage points (+6.0% vs. +2.3%), and the count of infant deaths was within 3.0 percentage points (+3.1% vs. +0.1%). Thus, it is unlikely that, for Fukushima, final death counts would show results markedly different from the finding that more Americans, especially infants, died than expected in the 14-week period following arrival of the Fukushima fallout.

The 14-week excess death projections after mid-March 2011 (13,983 total, 822 infant) are relatively similar to actual excesses in May–August 1986 (16,573 total, 306 infant).

Recent assessments have suggested that the amount of radioactivity released from Fukushima equals or exceeds that released from Chernobyl. Given the continuing emission of radioisotopes from the melted reactors, the high density of population around the plant, and the close proximity to food sources, we can expect that morbidity and mortality will be high in Japan. The relative homogeneity of the Japanese population will allow for comparison of health consequences for people living in areas with lesser and greater levels of contamination, as has been done in areas affected by Chernobyl (4).

Adverse health effects may also be expected in the United States, even though exposures have been far below those in Japan. Low-dose radiation exposure, previously assumed to be harmless, has been linked with elevated disease rates in children born to women who underwent pelvic X-rays while pregnant (18), Americans exposed to atomic bomb fallout (19), nuclear plant workers (20), and, for leukemia, children exposed to very low doses after Chernobyl (21). In addition to physical diseases is loss of cognitive ability in adolescents following low-dose ionizing radiation in utero (22).

The human fetus and infant are especially radiosensitive, given their rapid cell growth and cell division, as well as their small size that results in a proportionately larger dose. These exposures include X-ray, alpha, beta, and gamma radiation. Depending on the time of in utero radiation exposure, the result can be expressed as spontaneous abortion, premature birth, low birth weight, stillbirth, infant death, congenital malformations, and brain damage.

While this report concentrates on effects to humans, all life is sensitive to nuclear radiation exposure, including plants, fungi, insects spiders, birds, fish, and other animals (23). The best-studied group near Chernobyl (birds) shows a 50 percent decrease in species richness and a 66 percent drop in abundance in the most contaminated areas, compared with normal background in the same neighborhood (24).

More importantly, the findings reported here, plus the disease patterns that developed after Chernobyl, indicate that public health personnel can anticipate and plan to put in place diagnostic and treatment procedures. Given the continued high levels of radioactive iodine, it is predicted that the incidence of thyroid disease, including thyroid insufficiency in newborns and thyroid cancer in children and adults, will increase (4, 25).

The health effects of exposure to radioactivity from the Fukushima meltdowns, both in Japan and around the world, will take a long time to fully assess. The paucity of data from the U.S. EPA is unfortunate and will hamper future studies. A quarter of a century after the Chernobyl disaster, and more than 60 years after the bombings of Hiroshima and Nagasaki, compilations of health casualties are still being updated. It is critical that research should proceed with all due haste, as answers are essential to early diagnosis and treatment for exposed people, particularly children and the very young.

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Appendix Table 1

Iodine-131 and cesium-137 concentrations in U.S. milk, spring 1985 versus spring 1986

Date	Stations/ measurements		Average	Times vs. 1985
Iodine-131 concentrations				
May 1 to June 30, 1985	55	103	2.53	—
May 13 to June 23, 1986	68	563	14.15	5.6
May 13 to June 23, 1986				
Boise, ID	1	8	71.00	28.1
Spokane, WA	1	9	56.44	22.3
Helena, MT	1	10	33.30	13.2
Rapid City, SD	1	10	31.90	12.6
Seattle, WA	1	9	30.67	12.1
Salt Lake City, UT	1	10	29.70	11.7
Portland, OR	1	7	24.00	9.5
Cesium-137 concentrations				
May 1 to June 30, 1985	55	103	2.63	—
May 13 to June 23, 1986	68	563	9.47	3.6
May 13 to June 23, 1986				
Seattle, WA	1	9	39.33	15.0
Spokane, WA	1	9	29.44	11.2
Helena, MT	1	10	22.50	8.6
Boise, ID	1	8	21.38	8.2
Portland, OR	1	7	21.14	8.0

Sources: Office of Radiation Programs (6), Vols. 42 and 46.

Note: Averages are in picocuries of iodine-131 and cesium-137 per liter of pasteurized milk. I-131 has a half-life of 8.05 days; Cs-137 has a half-life of 30 years.

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Appendix Table 2

Change in total and infant deaths, January–April and May–August, 1985–1986

	1985	1986	% change
Infant deaths, final			
January–April	13,473	13,169	–2.3%
May–August	12,788	12,800	+0.1%
Infant deaths per 100,000, final			
January–April	1,123.55	1,091.49	–2.9%
May–August	985.36	989.56	+0.4%
Total deaths, final			
January–April	737,963	736,418	–0.2%
May–August	657,311	672,569	+2.3%
May–August 1985 and 1986, preliminary and final reported deaths			
Total deaths, preliminary	65,377	69,271	+6.0%
Total deaths, final	657,311	672,569	+2.3%
Infant deaths, preliminary	1,201	1,239	+3.1%
Infant deaths, final	12,788	12,800	+0.1%

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Appendix Table 3

Cities and weeks missing from mortality analysis
(*Morbidity and Mortality Weekly Report* indicated a "U" for unavailable)

Weeks 12–25

The analysis includes 119 cities (all 122 in the CDC report except Fort Worth, Texas; New Orleans, Louisiana; and Phoenix, Arizona). Of the 119 cities in the analysis, the following weeks had no reported data ("U" for unavailable), by week ending.

2010		2011	
3/27	El Paso, Texas	3/26	Worcester, Massachusetts
3/27	Somerville, Massachusetts	4/2	Duluth, Minnesota
3/27	Washington, DC	4/2	Minneapolis, Minnesota
4/3	St. Louis, Missouri	4/2	San Francisco, California
4/10	St. Louis, Missouri	4/2	St. Paul, Minnesota
4/10	San Jose, California	4/9	Duluth, Minnesota
4/17	San Jose, California	4/9	Minneapolis, Minnesota
4/17	San Jose, California	4/9	St. Paul, Minnesota
5/15	Detroit, Michigan	4/16	Duluth, Minnesota
5/22	Long Beach, California	4/16	Minneapolis, Minnesota
5/22	San Jose, California	4/16	St. Paul, Minnesota
5/29	Jersey City, New Jersey	4/23	Tucson, Arizona
6/19	San Francisco, California	5/7	Charlotte, North Carolina
		6/11	Paterson, New Jersey
		6/18	Baton Rouge, Louisiana
		6/25	Shreveport, Louisiana
13/1,666 = 0.78% missing		16/1,666 = 0.96% missing	
1,653/1,666 = 99.22% reported		1,650/1,666 = 99.04% reported	

Weeks 50 (prior year)–11

The analysis includes 104 cities (all 122 in the CDC report except Baton Rouge, Louisiana; Bridgeport, Connecticut; Camden, New Jersey; Charlotte, North Carolina; Chicago, Illinois; Cincinnati, Ohio; Detroit, Michigan; Fort Worth, Texas; Miami, Florida; New Orleans, Louisiana; Pasadena, California; Peoria, Illinois; Phoenix, Arizona; Pittsburgh, Pennsylvania; Rochester, New York; Trenton, New Jersey; Washington, DC; and Wichita, Kansas). Of the 104 cities in the analysis, the following weeks had no reported data ("U" for unavailable), by week ending.

2010		2011	
12/19	San Diego, California	12/18	Jersey City, New Jersey
12/26	Berkeley, California	12/18	Lansing, Michigan
12/26	El Paso, Texas	12/18	Paterson, New Jersey
12/26	Milwaukee, Wisconsin	12/18	Seattle, Washington

Appendix Table 3 (Cont'd.)

2010	(cont'd.)	2011	(cont'd.)
12/26	Newark, New Jersey	12/25	Houston, Texas
12/26	San Antonio, Texas	12/25	Seattle, Washington
1/2	Fort Wayne, Indiana	1/8	Columbus, Ohio
1/2	Jersey City, New Jersey	1/8	Somerville, Massachusetts
1/9	Cleveland, Ohio	1/22	New Haven, Connecticut
1/30	Columbus, Ohio	2/19	Columbus, Ohio
2/6	Kansas City, Missouri	2/19	Paterson, New Jersey
2/6	Seattle, Washington		
2/13	Jersey City, New Jersey		
13/1,456 = 0.89% missing		11/1,456 = 0.78% missing	
1,442/1,456 = 99.11% reported		1,445/1,456 = 99.22% reported	

Appendix Table 4

Calculation of significance of differences in 2010 and 2011 deaths

For example, in Table 2, the number of deaths rose 4.46%, from 148,395 to 155,015, from weeks 12–25 in 2010 versus 2011. This compared with a 2.34% increase from the prior 14-week periods. The significance of difference between the two means (+2.34% vs. +4.46%) was calculated using a *t*-test.

The formula $(O - E)$/SQRT $(\text{mean1}^2 + \text{mean2}^2)$ was used, assuming

O = observed increase (1.0446)
E = expected increase (1.0234)
N_1 = number of deaths for weeks 12–25, 2011
N_2 = number of deaths for weeks 50–11, 2011

Mean1 = 1/(SQRT N_1) × O = 1/(SQRT 155,015) × 1.0446 = 0.002653
Mean2 = 1/(SQRT N_2) × E = 1/(SQRT 148,395) × 1.0234 = 0.002657

The computations yield 0.0212/0.0037148, or a *z*-score of 5.71, which converts to a p value of < 0.000001 in any basic statistics table, meaning there is less than a 1 in 1,000,000 chance that the difference occurred due to random chance.

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