Asian Perspective 37 (2013), 523–549

A Public Health Perspective on the Fukushima Nuclear Disaster

Tilman A. Ruff

The Fukushima nuclear disaster is far from over and remains a global health concern. While evacuations, sheltering, reducing intake of contaminated food, and other measures reduced radiation exposures, both the immediate and longer-term public health responses to the disaster leave major room for improvement. Commercially and institutionally, vested interests have undermined public health and safety. ***Keywords:*** *Fukushima nuclear disaster, global public health, radiation risks, right to health.*

In this article I review key aspects of our knowledge about ionizing radiation and health, and I provide a public health perspective on priority measures to protect the people and environment affected by the Fukushima nuclear disaster. Because radioactive fallout spreads without regard to borders and affects people indiscriminately, any nuclear disaster that disperses radioactive materials in the air, soil, or water is of global concern. The public health aspects of the Fukushima disaster are therefore of global health significance. A disaster with uncontrolled radioactive release is possible at any nuclear plant.

Ionizing Radiation and Human Health

The Danger

Ionizing radiation is intensely biologically injurious, not because it contains extraordinarily large amounts of energy but because that energy is bundled and delivered to cells in large packets. The energy of a diagnostic X-ray, for example, is typically around 15,000 times as large as the energy of a chemical bond. Large complex molecular chains, especially of DNA, define to a considerable extent who we are, regulate many biological processes, and are both our most precious inheritance and the most vital legacy we pass on to our children. These large molecules are particularly vulnerable to disruption by the large packets of energy in ionizing radiation. The result is that a dose of ionizing radiation lethal to a human being can contain no more energy than the heat in a sip of hot coffee.

Ionizing radiation in doses over 100–250 milliSievert (mSv) causes acute effects detectable by common blood testing, and symptoms of acute radiation sickness develop at higher doses. Doses over 100 mSv cause a variety of both reversible and persistent effects in different organs. At all doses, without any threshold below which there is no effect, including doses too low to cause any short-term effects or symptoms, radiation exposure increases the long-term risk of cancer and chronic disease for the rest of the life of those exposed. The most recent published data from studies of Hiroshima and Nagasaki survivors confirm a linear dose-response relationship between radiation dose and cancer risk, with no threshold (Ozasa et al. 2012). The overall increase in risk of solid cancer incidence (occurrence) across a population is about one in 10,000 (and about half that for cancer deaths) for each 1 mSv of additional radiation exposure (NAS 2006). The increased risk for leukemia (blood cancer) is about 10 percent of this (NAS 2006).

The most widely accepted standard for radiation protection (excluding medical radiation) stipulates a maximum permissible dose of ionizing radiation for members of the public in nonemergency situations of 1 mSv per year. One mSv/year corresponds to about 0.11 microSv per hour, the most common unit of measurement of external radiation used in Japan after the Fukushima nuclear disaster. For workers exposed to radiation in the course of their occupation, the most widely accepted standard is for a maximum permissible level of 100 mSv over five years, with no more than 50 mSv in any one year. These limits are the statutory legal limits imposed by 1972 industrial safety regulation for nuclear industry workers in Japan. The Japanese Rules for Prevention of Damage from Ionizing Radiation stipulate that women should receive no more than 5 mSv over three months in occupational settings. The law also prohibits entry of ordinary citizens into "controlled areas" where the radiation level is higher than 1.3 mSv/quarter (5.2 mSv/year) and prohibits exposure of pregnant women to over 2 mSv/year in a controlled area (Grover 2012).

The widely accepted International Codex Alimentarius Commission food recommendations for radiation are for a maximum of 1 mSv per year exposure through food intake and assume that contaminated food constitutes a maximum of 10 percent of the diet. Doses below all of these levels of course do not equate with no risk.

Ionizing radiation also increases the risk of occurrence and death from some noncancer diseases, including cardiovascular and respiratory disease. This has been clearly demonstrated to occur at high doses, and recent evidence strongly indicates that circulatory disease mortality also increases at low total doses and dose rates, such as occur in many nuclear industry workers. The increased risk of death from heart and other circulatory diseases is comparable in magnitude to the radiation cancer risk, meaning that the total extra risk of dying because of exposure to radiation is likely to at least double the increased risk of death from cancer alone (Little et al. 2012).

High-Risk Individuals

Particularly relevant to Fukushima is that radiation risk is not uniform. Infants are about four times as sensitive to radiation cancer-inducing effects as middle-aged adults (NAS 2006; NAIIC 2012). A single X-ray to the abdomen of a pregnant woman, involving a radiation dose to the fetus of about 10 mSv, has been shown to increase the risk of cancer during childhood in her offspring by 40 percent (Doll 1997; NAS 2006). Females are overall at close to 40 percent greater cancer risk as males for the same dose of radiation, and this difference is greatest in young children (NAS 2006). For cardiovascular disease risk, the most recent systematic review and meta-analysis indicate that the increased lifetime risk of death from circulatory disease estimated for the British population is about ten times higher for a child exposed to radiation before ten years of age compared with exposure occurring after age seventy. In the same study, the risk of death from solid cancer following radiation exposure before age ten was estimated at more than twenty times the risk for exposures occurring above age seventy (Little et al. 2012). These differences relate to both increased sensitivity in the young and the generally longer remaining years of life for effects to become manifest.

To provide a perspective on these risks, for a child born in Fukushima in 2011 who was exposed to a total of 100 mSv of additional radiation in its first five years of life, a level tolerated by current Japanese policy, the additional lifetime risk of cancer would be on the order of one in thirty, probably with a similar additional risk of premature cardiovascular death.

The main long-term radioactive contaminant is cesium (Cs)-137, with a physical half-life of thirty years, and an effective biological half-life that may be longer, because cesium behaves chemically like potassium. Cesium is bio-concentrated and recycled by plants and animals, especially in natural ecosystems like forests. Therefore, in the absence of effective remediation, in contaminated areas radiation levels will decline slowly over many decades, and the amount of Cs-137 will have decayed to one thousandth of the initial amount only after 300 years. Areas where people live and work tend to be in lower-lying, flatter areas vulnerable to accumulation of cesium with runoff from adjacent hillsides and along waterways (NAIIC 2012).

Women who are carriers of BRCA1/2 gene mutations, which put them at high risk of developing breast cancer, have recently been shown to have heightened sensitivity to increased cancer risk from exposure to radiation (Pijpe et al. 2012). Other genetic markers of increased vulnerability to cancer induction from radiation largely remain to be characterized.

A consistent and continuing trend in our understanding of radiation health effects has been that the more we know, the greater the risks. Radiation risk estimates and radiation protection standards have always been raised, never lowered. New evidence continues to emerge of radiation health effects beyond those expected. Some recent examples include the largest study to date of nuclear industry workers, conducted by the International

Agency for Research on Cancer and involving over 400,000 workers in fifteen countries. The study produced estimates of cancer risk two to three times higher than linear extrapolations from findings in atomic bomb survivors, despite over 90 percent of workers receiving cumulative doses less than 50 mSv (Cardis et al. 2005). These findings are not supportive of the reduced harm often assumed to apply for a given radiation dose delivered over a longer rather than a shorter period of time. The most recent data from Japanese *hibakusha* (atomic bomb survivors) show an unexpected trend of increased risk for a given radiation dose at low doses, in addition to a linear dose-response relationship of increasing cancer cases throughout life with no evidence of a threshold of radiation dose below which no risk was found (Ozasa et al. 2012).

A recent study of cancer risk following exposure to computed tomography (CT) scans among children and adolescents in Australia is the largest population-based study to date of diagnostic medical radiation exposure and provides more information about low-dose exposures than was available from studies of Japanese atomic bomb survivors (Mathews et al. 2013). In this study, the increase in cancer risk was already apparent in the one to four years after first exposure, a finding of particular relevance to thyroid cancer among children after the Fukushima disaster. The study found a risk for solid cancer other than brain cancer around ten times higher than that documented in young *hibakusha*, and with greater statistical precision. This finding is consistent with the overwhelming weight of other data indicating that the *hibakusha* studies underestimate the risk of low-dose radiation exposure.

There has been some confusion and misinterpretation about the genetic consequences of ionizing radiation exposure across generations. Clearly, radiation is a powerful cause of genetic damage. Many genetic effects are also heritable, and genetic influences on disease occurrence are often complex, interact with environmental factors, and affect multiple body systems. Previously, studies of children born to those exposed to the nuclear bombings in Hiroshima and Nagasaki have not demonstrated an increase in diseases attributable to radiation-induced mutations.

However, there is extensive evidence of radiation-induced transmissible mutations in other animals, and there is no reason to believe humans are immune to such harm (NAS 2006). Evidence is emerging on an increased risk of leukemia in children whose parents were both exposed to the atomic bombings in Japan (Goto 2012).

Radiation Release from the Fukushima Daiichi Nuclear Plant

The quantity of radioactive material at the Fukushima Daiichi (FD) site at the time of the disaster was enormous. In all, 1,760 tons of reactor fuel were present at the site in March 2011, in comparison with the 180 tons in the Chernobyl reactor at the time of the disaster there in April 1986. A particularly unfortunate aspect of the design of the FD plant is the location of the spent fuel ponds immediately above and in the same building as the reactors, making them highly vulnerable to mishaps with the reactors. These pools contained 70 percent of the total radioactive inventory at the site (Stohl et al. 2011), and a high proportion of long-lived isotopes, in large open pools without multiple engineered layers of containment that reactors have. They are separated from the outside only by the walls and roof of a building.

An authoritative independent international analysis (Stohl et al. 2011) found compelling evidence that leakage of radioactivity commenced after the earthquake struck and before the tsunami hit. This nuclear disaster therefore has relevance for all nuclear power plants in Japan and globally, even those not located near coasts.

Independent international estimates suggest that the total quantity of Cs-137 released into the atmosphere by the multiple explosions and fires in the first week following the disaster amounted to 35.8 petaBecquerel (PBq, 10^{15} Bq), 42 percent of the estimated emission from the Chernobyl disaster (Stohl et al. 2011). It has been estimated that around half of the cesium released was Cs-134, with a half-life of two years, and the rest was Cs-137 with a half-life of thirty years. The fallout was deposited rather widely in eastern Honshu, with hotspots related to deposition by rain and snow as well as concentration through water runoff. The largest radioactive fallout cloud went over Japan on March 14–15, 2011, but luckily it did not rain at this time. Had it rained on that night over Tokyo, the evacuation of the 30 million inhabitants of the greater Tokyo area may well have become necessary. If substantial radioactive fallout had been carried to the west over the neighboring highly populated areas of Korea and China, the public health and international ramifications of the disaster could have been far worse.

It has been estimated that up to April 20, about 19 percent of the cesium emitted into the atmosphere was deposited on Japanese land, about 2 percent on land elsewhere, and the rest largely over the northern Pacific Ocean (Stohl et al. 2011). Radioactive contamination from the accident spread over the whole of the Northern Hemisphere's atmosphere by March 22. One international estimate of the Cs-137 marine release between March 21 and July 18, 2011, was 27 PBq (Bailly du Bois et al. 2012), though most estimates are between 3.5 and 15 PBq (Buesseler 2013). Radioactive seepage and leakage into soil and ocean continue. Large volumes of contaminated cooling water spilled into the base of the reactor buildings and continue to accumulate onsite. Monitoring of radioactivity in fish caught off the east coast of Honshu showed much slower than expected decline in cesium levels in bottom-dwelling fish from May 2011 to January 2013, implying that cesium was still being released into the marine food chain (Buesseler 2012; 2013).

Public Health Needs in the Aftermath of the Fukushima Nuclear Disaster

Good Governance

The failures of good governance and due diligence associated with the Fukushima nuclear disaster, and the regulatory and operational deficiencies that enabled it to happen, are profound and have wide ramifications. They have been commendably analyzed and documented in a number of major independent reports, including those of the Rebuild Japan Foundation and the first-ever independent commission chartered by the Diet, the Fukushima Nuclear Accident Independent Investigation Commission (NAIIC 2012).

Some of the key conclusions of the commission highlight the lack of priority given to the well-being and safety of all Japanese citizens, the first responsibility of any government (NAIIC 2012). The accident, said its report, "was the result of collusion between the government, regulators and TEPCO [Tokyo Electric Power Company] . . . They effectively betrayed the nation's right to be safe from nuclear accidents." The commission concluded that

> the government and regulators are not fully committed to protecting public health and safety; that they have not acted to protect the health of the residents and to restore their welfare. The regulators did not monitor or supervise nuclear safety. . . . Their independence from the political arena, the ministries promoting nuclear energy, and the operators was a mockery. They were incapable, and lacked the expertise and the commitment to assure the safety of nuclear power. Across the board, the Commission found ignorance and arrogance unforgivable for anyone or any organization that deals with nuclear power. We found . . . a disregard for public safety.

Dr. Kiyoshi Kurokawa, the commission chair, made a number of very direct accusations in his introduction to the commission's report:

> It was a profoundly manmade disaster—that could and should have been foreseen and prevented. . . . A multitude of errors and willful negligence that left the Fukushima plant unprepared for the events of March 11. . . . Bureaucrats . . . put organizational interests ahead of their paramount duty to protect public safety.

Kurokawa also emphasized the ongoing risk of further mishaps and radioactive releases at the already severely damaged FD plant, now more vulnerable to further damage from continuing aftershocks, and also at the many other nuclear facilities in Japan:

> Transparent, accountable, efficient, and competent governance processes that eliminate corruption and conflicts of interest are more important for nuclear technology than in any other field given its destructive capacity in terms of health and use in producing nuclear weapons. It is crucial that public health and safety receive the highest priority in governance processes, without regard to political, institutional, and other vested interests. (NAIIC 2012)

Radiation Protection

As highlighted by commission chair Kurokawa, a vital priority is to prevent further radiation release from the damaged FD plants and also from other nuclear power plants (NPPs). Establishing and maintaining robust, stable, continuous, closed-loop cooling of the damaged FD reactors and spent fuel ponds, moving as much spent reactor fuel as possible as quickly as possible from cooling ponds to dry cask storage, installing physical barriers to radioactive materials both around the damaged reactor buildings and underground, and removing reactor fuel and decommissioning the damaged reactors as rapidly as feasible are all changes that are needed in Japan's NPPs. These changes are all the more essential since all the damaged reactors suffer from many of the same location, design, regulatory, and operational problems that were present in Fukushima.

Including FD reactors 1, 2, and 3, a total of twelve known nuclear reactor accidents have involved fuel damage or partial core meltdown with release of radioactivity from the reactor core. These have occurred with different reactor types in Canada, Germany, Japan, Great Britain, Ukraine, and the United States (Cochran 2011). Eleven reactors produced electricity; some were also used to produce plutonium for nuclear weapons. The historic frequency of core melt accidents is one in 1,300 years of reactor operation. For boiling water reactors with Mark one- or two-type containment structures, like the FD reactors, the frequency of such accidents is one in 630 reactor years (Cochran 2011). In addition, there have been many near misses. On this basis, we may say that core melt incidents can be expected every fifteen to twenty years at one of Japan's fifty-four nuclear power reactors.

The requirements for safe nuclear power would include a level of technical reliability, security, and control that has never been achieved anywhere. Shutting down all nuclear power reactors and transferring spent reactor fuel from ponds to dry cask storage as quickly as possible would reduce the danger of further similar disasters triggered not only by natural events but by deliberate attack. One obvious lesson from Fukushima is that reactors and spent fuel ponds can generate catastrophic radiation releases not only through direct structural damage but also through disruption to continuous cooling through loss of water supply or power for pumps. Disruption of those kinds could be triggered by an earthquake or tsunami, but also deliberately, by insider or external attack or a combination of both.

Safety Measures

A key underpinning of the severely deficient public health response to the Fukushima nuclear disaster was the lack of adequate preparation. Unwillingness on the part of regulatory and government authorities to acknowledge and act on the real possibility of accidents and unforeseen mishaps was the principal reason.

Not only is Japan, at the confluence of three tectonic plates, one of the most earthquake-prone regions on Earth; severe earthquakes are all too frequent. In the twentieth century eleven earthquakes greater than 8.5 in magnitude took place, and only thirteen years into the twenty-first century there have already been five earthquakes of this magnitude (Park 2011). Most of these have been accompanied by tsunamis. Previous tsunami run-up heights in Eastern Honshu have been as much as 38 meters in 1896 (the maximum wave height recorded in the March 11, 2011, tsunami was 38.9 meters), and 29 meters in 1933 (NOAA 2013). The occurrence of a tsunami that would inundate the FD plant was therefore entirely predictable.

Accidents will happen, and preparation needs to be made for them. Preparation requires clear, regularly reviewed and updated, well-communicated, and regularly exercised plans for evacuation of workers and populations most likely to be affected by accidents. It also requires predistribution of stable iodine, which must be undertaken either shortly before or within a few hours of exposure to radioactive fallout. Following the Fukushima disaster, iodine was either not available or not effectively used in a timely fashion for most of those who needed it; only about 10,000 residents were able to take iodine (NAIIC 2012). Most workers and local residents had no prior training in evacuation procedures. Evacuations were poorly managed and largely uncoordinated. Available information, both from the Japanese government's SPEEDI radiation monitoring and prediction system and from US airborne radiation monitoring, was not used to guide evacuations. Communications between national, prefectural, and local government broke down, completely in some cases at critical moments. In consequence, evacuations were needlessly delayed, sometimes by weeks or months. They often had to be repeated, with some residents moving more than six times. And some residents (such as from Namie) unfortunately moved into more contaminated areas than those they had left.

Effective nuclear accident preparedness plans, such as for timely, effective evacuation and distribution of stable iodine, are not only required in areas near the FD plant but also near all other nuclear plants in Japan. These plans should be put in place expeditiously and should extend at least fifty kilometers from nuclear facilities. The International Atomic Energy Agency (IAEA), the US Nuclear Regulatory Commission, and many other national authorities recommended an eighty-kilometer exclusion zone for their nationals following the Fukushima disaster. Had Japanese authorities designated such an evacuation zone (containing 2 million residents), radiation exposure for hundreds of thousands of people could have been substantially reduced.

Reduction of Levels of Radiation

Following the Chernobyl disaster and the breakup of the former Soviet Union, zoning criteria were applied to radioactively contaminated areas in Belarus, Russia, and Ukraine on the basis of the estimated annual radiation dose associated with various levels of Cs-137 contamination, the main radioisotope causing radiation exposure in the longer term (ICRP 2009b; NAIIC 2012). Areas with more than 1,480 kBq Cs-137 per m^2, where residents would be expected to receive more than 5 mSv of additional radiation exposure per year, were designated for priority and compulsory resettlement. Around Chernobyl, 3,100 km^2 were contaminated at this level, compared with 1,778 km^2 in Fukushima. In Fukushima, the areas most contaminated with Cs-137 include extensive populations, including the cities of Koriyama (population 336,000), Fukushima (population 290,000), and Nihonmatsu (population 60,000). Yet the radiation exposure reduction measures being taken in many of these areas, in modern Japan, are less than those applied over twenty years ago for populations surrounding Chernobyl.

The Remediation Roadmap released by the Japanese government on January 26, 2012, the most recent cleanup standard for Japan available in English (in summary form) on the IAEA website as of June 2013, does not call for evacuation of those living in areas where they would be expected to receive additional radiation exposure of up to 20 mSv per year (IAEA 2012). The commission noted that the basic government policy on decontamination aims to reduce annual exposure for the public by approximately 50 percent in contaminated areas within two years, including at least 10 percent through decontamination work. For children the target is to reduce the exposure within two years by 60 percent, including by at least 20 percent through decontamination (NAIIC 2012). The UN Special Rapporteur (SR) on the right to health, in his May 2013 report to the UN Human Rights Council, urges a clear time-bound plan to reduce exposures to less than 1 mSv/year (Grover 2013). Disappointingly, the Japanese government's response states that in areas with less than 20 mSv/year, reduction of additional exposure to less than 1 mSv/year is a long-term goal. But the government makes no specific commitment other than to formulate policy after FY2013 on the basis of results in the first two years (GOJ 2013).

On May 23, 2012, the World Health Organization released a report on preliminary radiation dose estimates following the Fukushima disaster (WHO 2012a). It covers data available through mid-September 2011 and excludes doses within twenty kilometers of the FD plant, including to plant workers. The report also does not estimate doses for embryos, fetuses, and breast-fed infants, even though these groups are among those at highest risk of radiation harm. The doses, estimated in the WHO report in the most contaminated areas outside twenty kilometers (Namie, Iitate, and Katsurao) for the first four months following the disaster, are 10–50 mSv for adults and children, including infants, with 80 to 90 percent of the dose coming from external radiation from fallout deposited on the ground. In the rest of Fukushima Prefecture, doses over the first year are estimated in the range of 1–10 mSv. In the neighboring prefectures of Chiba, Gunma, Ibaraki, Miyagi, and Tochigi, first-year doses in the range of 0.1–10 mSv are estimated, with 80 percent being external. In the rest of Japan, estimated first-year doses are 0.1–1 mSv, with 70 percent coming from ingestion (mostly from food and drink).

The WHO released another report in February 2013, which estimates the health risks associated with the exposures estimated in its 2012 report (WHO 2013). Those in the most affected locations, Namie Town and Iitate Village (27,100 people evacuated), were estimated to have received effective doses in the first year of 12–25 mSv. Lifetime risks for leukemia are predicted to increase by up to 7 percent in males exposed as infants; lifetime breast cancer risk for females exposed as infants to increase by 6 percent; solid cancer risk for females exposed as infants is predicted to increase 4 percent; and for thyroid cancer for females exposed as infants, the risk is estimated to increase by 70 percent.[1]

While the methodology used was deliberately chosen to avoid underestimation of risks, these estimates might prove to be underestimates for a number of reasons. The radiation dose information used only extended to September 2011 and therefore does not consider additional exposures, such as from continuing leaks from the damaged reactors or exposures of additional plant workers. As noted, postdisaster worker exposure data are incomplete. First responders—police, fire, and military personnel—were excluded. Doses received by members of the public within the twenty-kilometer exclusion zone around the FD plant were also excluded, even though some residents within this zone did not evacuate for some days after the disaster, when radiation doses were high (NAIIC 2012).[2]

The report notes that no local cancer incidence rates for Fukushima Prefecture were available, and that the Fukushima cancer registry began only in 2011. These issues do not bode well for effective monitoring of cancer incidence in Fukushima Prefecture after the disaster. No estimates are made for exposure outside Fukushima Prefecture, yet the previous WHO report estimates that first-year committed effective doses for people in the neighboring prefectures of Chiba, Gunma, Ibaraki, Miyagi, and Tochigi were in the range of 0.1–10 mSv (WHO 2012a). Also ignored are exposures in the rest of Japan, which, while small, affect large numbers of people.

A number of measures can be recommended to protect people as much as feasible from the radioactive contamination already released. Because radioactive material decays over time, reducing exposure early rather than later provides greater benefit. Comprehensive mapping of estimated radiation exposure is associated with residence in all of the more than minimally contaminated areas. Given the significant local variation that can occur, this mapping needs to be done accurately and consistently, street by street, with the findings easily and promptly available to the public. Such basic information is people's right, essential for making informed decisions about their future. While 3,200 radiation monitoring posts have been established across Fukushima prefecture, these are generally located on concrete and crushed rock bases where decontamination of the immediate area has occurred. Radiation levels measured several meters away are generally higher than at the monitoring posts. Such factors do not justify confidence in officially reported radiation levels. Mapping should be performed periodically to monitor trends over time and should include representative surveys of whole body measurements for internal radiation exposure, recommended by the SR to be available without restriction (Grover 2013).

All measures related to radiation protection should be implemented across all contaminated areas and determined according to the level of contamination, not distance or prefectural or other artificial boundaries. At present, most measures—including, for example, all health surveys and disaster-related health activities—are undertaken only in Fukushima Prefecture, whereas several neighboring prefectures include areas more contaminated than parts of Fukushima.

In general, with possible exceptions for elderly people able to make informed decisions, people should be supported to relocate from areas where their radiation exposures are estimated to be more than 5 mSv/year. For those at greatest risk of radiation harm, and now well beyond the initial emergency phase of the disaster, the obligation to protect the most vulnerable provides an imperative that children and fetuses not be exposed to additional avoidable and unjustified radiation of greater than 1 mSv/year.

The government has an obligation to provide comprehensive assistance for those who choose or are compelled to relocate, including finance, housing, education, and employment. While the Diet's passage of the Act on the Protection and Support for the Children and Other Victims of the TEPCO Disaster in June 2012 is to be welcomed, as of May 2013 the act has not yet been implemented, and the government is still "studying it" (GOJ 2013). Implementation should be carried out immediately. To date, in the absence of widely available needs-based assistance and compensation, considerable inequity has occurred in relation to individuals' and families' ability to protect themselves from radiation, such as through relocation or decontamination. For example, many who can afford to do so may have relocated or replaced their house roof, external surfaces, and paving, whereas many poorer people have not been able to relocate or afford such decontamination measures.

Regarding radioactivity in food, the gradual replacement between April 2012 and January 2013 of provisional food standards with new stricter limits is to be welcomed. However, more extensive monitoring and more effective enforcement are widely perceived as necessary, including by the UN SR (Grover 2012). Wide monitoring of marine-sourced foods will be required given the bio-concentration, which occurs for a number of radionuclides, including cesium and strontium isotopes, and the demonstrated capacity for migratory marine species to carry radioisotopes over long distances, such as Bluefin tuna carrying Cs-134 and 137 from the Fukushima coast to California (Madigan, Baumann, and Fisher 2012). The Fukushima Health Management Survey drew attention to the earlier "chaos" in the food testing systems and to the fact that the new food standards (based on a 1-mSv upper public dose limit) are drafted on the basis of considering radiation exposure only through food, ignoring additional exposure through pathways such as external exposure (Committee on Fukushima Health Management Survey 2013).

Allowing Informed Choices

Full transparency and timely communication regarding all aspects of the nuclear disaster and its effects are required as a basic right—essential for good governance, for people's ability to make informed choices about their future, and for shared partnership in public health. The need for full, prompt disclosure has been emphasized by each of the independent bodies examining the disaster. It needs to cover all aspects, including the status of the reactors and fuel ponds, seismic activity, radiation releases, public health risks and responses, and the results of long-term radiation monitoring of land, sea, animals, plants, food, and freshwater. All such information should be available promptly, in a user-friendly and readily accessible format, and in both Japanese and English.

Information should also be accurate and impartial. The extent of co-option, collusion, and corruption by the Japanese government-bureaucratic-regulatory-commercial "nuclear village" runs alarmingly wide and deep. Even among physicians with a solemn professional ethical obligation to act in their patients' and the population's best health interests, I have come across repeated instances of physician colleagues in Japan compromising their professional responsibility and independence in order not to criticize the government, often out of fear of negative effects on their positions and employment prospects. This behavior is unacceptable.

The most widely regarded, independent, rigorous assessments of ionizing radiation and health are the Biological Effects of Ionizing Radiation (BEIR) reports of the US National Academy of Sciences. The whole purpose of the most recent BEIR VII report, all 710 pages of it, is the characterization of the health effects of low linear energy transfer radiation (excluding heavier and more energetic particulate radiation such as alpha particles and neutrons) in low doses—less than 100 mSv (NAS 2006). Some scientists, physicians, and professional organizations have been complicit in misinformation; for example, various Japanese government publications, including booklets for schools, have informed the public that there was no proven risk of cancer or other health harm for radiation doses less than 100 mSv. This is still the official position of the Japanese government (GOJ 2013)—a clear misrepresentation of overwhelming scientific evidence and authoritative recommendations (for example, NAS 2006), evidence from the Hiroshima and Nagasaki *hibakusha* (Kodama et al. 2012; Ozasa et al. 2012), and Japan's own radiation protection standards. The UN Special Rapporteur clearly expressed his concern at such misinformation, as did the Diet, and highlighted the public's need for and right to accurate, independent information (Grover 2012; NAIIC 2012).

Health Monitoring

Long-term monitoring of the health of those exposed to radiation from the FD plants is important to understand the effects, provide optimal advice, and guide health and other service provision to best meet people's needs.

The $1.2 billion allocated for the Fukushima Health Management Survey is planned to support the basic survey and three specific surveys (Yasumura et al. 2012). The basic survey is intended to collect information on location, housing, and behavior for all the 2.05 million population residing or working in Fukushima Prefecture during the March 11 to July 11, 2011, period. This survey relies on recall; it is very complex and demanding to derive estimates of external radiation dose for the first four months following the disaster (Radiation Medical Science 2013). As of March 31, 2013, the overall response rate was stable at only 23.4 percent (Radiation Medical Science 2013). For 94.9 percent of about 392,000 respondents, excluding radiation workers, their estimated external radiation dose over the first four months following the disaster was less than 2 mSv, and for 99.8 percent the estimated external doses over the first four months were less than 5 mSv (Radiation Medical Science 2013). Despite this low response rate, inevitable questions about its representativeness, and the central importance of dose estimates to assessing long-term health impacts, the government does not believe it is reasonable to make further efforts to increase the response rate of the health management survey (GOJ 2013).

The three detailed surveys include comprehensive health checks planned for all 210,000 residents of the government-designated evacuation zones, a mental health and lifestyle questionnaire survey to identify mental health and lifestyle issues for initial telephone counseling, and a pregnancy and birth survey to gather information on pregnancy outcomes for the almost 16,000 women in Fukushima who requested Mother's Books (almost universally requested by women in Japan who become pregnant) between August 2010 and July 2011.

Effective evaluation of the long-term health consequences of the Fukushima nuclear disaster requires a comprehensive register of those who have been exposed to radiation so that long-term data on their health outcomes can be analyzed in relation to their radiation exposure. Such a register and dose assessment should be established as soon as possible, and unlike the situation in Hiroshima and Nagasaki, will need to assess ongoing radiation exposure. A considerable number of population-based registers around the world, for various purposes such as immunization, cervical smear, and mammography screening, demonstrate that they can be established while respecting privacy and confidentiality. It would seem clear that means other than the current basic survey will be needed to develop a comprehensive population register of exposed persons with estimated doses (or dose bands).

The survey and additional health-care provisions should be extended to all radiation-affected areas, including those outside Fukushima Prefecture. Radiation dose assessments used in health studies will need to be updated and should not only cover the initial months after the disaster but also reflect internal and external exposures. The Diet commission particularly emphasized the need for systematic, long-term internal exposure monitoring using whole body counters (WBC), currently not included in health monitoring surveys (NAIIC 2012). While we do not know how representative the results are, reported WBC monitoring conducted on 123,050 Fukushima residents between June 2011 and April 2013, generally in areas of lower contamination, found more than 99.9 percent of people with effective committed internal doses less than 1 mSv (Fukushima 2013).

Cancer registries in many prefectures in Japan, including in Fukushima, are identified by Japanese researchers as being far from ideal and may not be of sufficient comprehensiveness or quality to allow effective cancer surveillance and monitoring of trends (Akiba 2012; Yasumura et al. 2012). Akiba notes that the regional cancer registry in Fukushima was only established in April 2010, that metropolitan Tokyo lacks a cancer registry, and that the International Agency for Research on Cancer reports fewer than ten prefectural cancer registries among the forty-seven prefectures in Japan (Akiba 2012). This severely hampers the ability to monitor trends and changes in the important health outcome of cancer.

The only specific long-term health outcomes currently included in the Fukushima Health Management Survey are thyroid disease in children—certainly appropriate in light of the epidemic of thyroid cancer in children that began four to five years after the Chernobyl disaster—and planned long-term linkage of the survey database with cancer registry data. However, as described previously, cancer is not the only long-term disease outcome associated with radiation. Chronic disease, especially cardiovascular disease, and (indirect) long-term adverse effects on mental health are also well documented. Therefore, as recommended by the UN Special Rapporteur, health outcome evaluation after the Fukushima disaster should be both comprehensive and long term (Grover 2012). The responsibility to adequately study long-term health outcomes from the Chernobyl disaster failed to be undertaken. It would be a tragic disservice to public health and especially to those harmed by the Fukushima nuclear disaster if the opportunity to set up high-quality, long-term, comprehensive, prospective health evaluation is not seized.

As noted by the UN SR, the right to health framework requires the state to ensure the participation of all communities in decisions that affect them (Grover 2012; 2013). The SR urged the government to ensure that affected people, particularly the vulnerable groups, are fully involved in all decisionmaking processes, including the formulation of health management surveys, design of evacuation shelters, and implementation of decontamination. This involvement is especially important at a time when confidence in governments and officials in Japan has been severely shaken. Moreover, inasmuch as the Fukushima disaster is of global dimensions and concern, health monitoring would benefit from ongoing involvement of international experts in all facets of study design, planning, implementation, and analysis. All these would benefit from a high degree of transparency and independent international peer review (Akiba 2012).

Protecting and Monitoring Nuclear Industry Workers

While children are the population group most vulnerable to the effects of radiation, nuclear industry workers are at risk of greatest radiation exposure. Yet their monitoring and protection has historically been and remains to this day severely neglected. There are large numbers of nuclear industry workers, and whatever the future of nuclear power in Japan, large numbers will be required in the future, including for at least several decades for the cleanup, stabilization, and decommissioning of the FD reactors. In 2009, according to the Nuclear and Industrial Safety Agency (NISA), there were 1,108 regular employees and 9,195 contract employees at the FD plant (Jobin 2011). Typical of the nuclear industry in Japan, the vast majority (over 80 percent) of workers are day laborers, engaged in up to eight levels of subcontracting (Jobin 2012). By October 2012, TEPCO reported that over 24,000 men had been involved in FD site cleanup (Hecht 2013).

As well as reducing staff costs, this heavy reliance on a transient informal workforce is negative for worker protection and radiation safety. According to NISA, in 2009, 671 people who received a radiation dose between 5 and 10 mSv were contract laborers, while only thirty-six were regular employees. Those who received between 10 and 15 mSv comprised 220 contract laborers and two regular workers, while thirty-five contract workers and no regular workers were exposed to between 15 and 20 mSv (Jobin 2011). These workers are generally poorly trained and subject to poor occupational health and safety practices; they undertake the least skilled and dirtiest work and receive the highest radiation exposure (Jobin 2011; 2012; Hecht 2013). Both before and after the disaster, consistent reports circulated of subcontractors' dosimeters being unavailable, not used, deliberately left in less contaminated areas, or in one instance, shielded in lead-lined cases (Hecht 2013), all in order to falsely minimize apparent exposures and allow workers to keep working despite excessive radiation exposures.

The Diet commission found that for workers at the FD site at the time of the disaster (NAIIC 2012), about 30 percent of all workers were never notified of their cumulative radiation dosage. About 40 percent of TEPCO employees received a warning that the reactors were or could be in a dangerous state, whereas virtually none of the contractors did. Before March 11, 2011, only 67 percent of TEPCO staff and 10 to 11 percent of contractors had received any explanation of what they may be tasked to do in response to an accident; 28 percent of TEPCO workers and 38 to 44 percent of contractors did not consent to be involved in the accident response but had no option.

Without independently monitored and enforced standards of worker protection, it is reportedly common practice for subcontractors to move from one nuclear facility where they have accumulated a near- or above-permissible radiation dose to another one, and thus accumulate further exposure. This may occur repeatedly. These factors mean that occupational radiation exposures documented in Japan are likely to be grossly incomplete and substantially underestimate real exposures.

Improvement of occupational health and safety standards for all nuclear industry workers, most particularly those redressing the inequitable gap in standards and protection for subcontractors, is urgent in the context of the massive and continuing cleanup work required in Fukushima. Another overdue need is a national lifetime radiation exposure register for all nuclear industry workers, managed by a public health agency independent of the industry, as exists in a number of other countries. Workers should have ready access to their exposure data.

The Right to Health

The constitution of the World Health Organization enshrines the highest attainable standard of health as a fundamental right of every human being. The right to health does not mean a right to be healthy, but it does mean that states have an obligation to generate conditions in which everyone can be as healthy as possible (WHO 2012b). Every state has ratified at least one international human rights treaty recognizing the right to health (OHCHR 2008).

The right to health is an inclusive right: "Health is a fundamental human right indispensable for the exercise of other human rights" (UN ECOSOC 2000). The International Covenant on Economic, Social and Cultural Rights identifies "the underlying determinants of health," including safe water and adequate sanitation, safe food, adequate nutrition and housing, healthy working and environmental conditions, health-related education and information, and gender equality (OHCHR 2008). Article 12.2(b) of the covenant on "the right to healthy natural and workplace environments" includes "the prevention and reduction of the population's exposure to harmful substances such as radiation and harmful chemicals or other detrimental environmental conditions that directly or indirectly impact upon human health" (United Nations Economic and Social Council 2000).

Another core obligation of states is the implementation of a national public health strategy and plan of action, giving particular attention to all vulnerable or marginalized groups (WHO 2012b). Participation of the population in health-related decision-making at national and community levels is also a key element of the right to health (OHCHR 2008).

A human-rights lens can provide a valuable perspective in addressing public and occupational health consequences and needs from the Fukushima nuclear disaster. In his November 2012 visit to Japan and in his report to the UN Human Rights

Council, Special Rapporteur Anand Grover made a number of important recommendations based on consideration of these international human rights in the context of the Fukushima nuclear disaster, some referred to above (Grover 2012; 2013). But there are other human rights dimensions to nuclear power. A so-called inalienable right of nations to the "use of nuclear energy for peaceful purposes," articulated in Article IV of the Nuclear Non-Proliferation Treaty, in reality means exposing people and other living things worldwide to a risk of indiscriminate, catastrophic radioactive contamination at any time. Nuclear power erodes the health and rights of future generations. Through its inevitable generation of plutonium, and the intrinsic potential of uranium enrichment plants to enrich uranium beyond reactor grade to weapons grade, nuclear power exacerbates the danger of nuclear war and its catastrophic human consequences. Nuclear power thus undermines fundamental human and biosphere rights, responsible custodianship, and human security.

Were Eleanor Roosevelt coordinating the drafting of the Universal Declaration of Human Rights today, one would hope that the rights of future generations; the right of people everywhere to safe, renewable energy sources; and the right to be protected from preventable, indiscriminate, transgenerational radioactive contamination would be included. These human rights strengthen rather than undermine global health.

Conclusion

The harnessing of nuclear energy for bombs and electricity, deeply intertwined in their history, materials, and processes, pose challenges that are global, extend over geological time, and are unparalleled in their potential ferocity. They require a long-term, evidence-based approach. In the words of commission chair Kurokawa, "Accidents will occur, machinery will break down, humans will err" in nuclear as in all other matters (NAIIC 2012).

The recommendations described in this article are based on well-established public health principles, including "first, do no harm," informed consent, respect for human rights and dignity, "nothing about us without us," and prevention of catastrophic consequences that cannot be managed or controlled. Nuclear bombs, stockpiles of fissile materials, and nuclear power reactors vulnerable to attack and catastrophic accidents like in Fukushima are not compatible with a global human future that is healthy and sustainable.

I must close with a personal note. I am very sorry that much of the radioactive fallout contaminating significant areas of land and sea and harming people in Japan comes from Australian uranium, which was in at least five of the six Fukushima Daiichi (FD) nuclear reactors (Floyd 2011). This uranium was mined at the Ranger uranium mine located within the World Heritage Kakadu National Park, against the strong and consistent opposition of the traditional Aboriginal custodians, the Mirrar people.

Notes

Tilman A. Ruff is associate professor in the Nossal Institute for Global Health, University of Melbourne, and copresident of International Physicians for the Prevention of Nuclear War. His research has appeared in *The Lancet, Bulletin of the World Health Organization, Journal of Infectious Diseases, Vaccine, Bulletin of the Atomic Scientists,* and the *British Medical Journal*. He can be reached at tar@unimelb.edu.au.

1. For people in the second most affected region (including the city of Fukushima, population 290,000 [2010], and Koriyama, population 334,400 [2010]) the estimated additional lifetime cancer risks are about half those in the highest dose region; and for the third most exposed region, with preliminary estimated effective radiation doses of 3–5 mSv, the increased lifetime cancer risks are estimated to be one-quarter to one-third of those most exposed. Among nuclear plant emergency workers, lifetime risks for leukemia, thyroid cancer, and all solid cancers are estimated to be increased; however, only first-year doses are considered for workers. For the small number of young workers with the highest exposures (data provided by TEPCO), the risk of thyroid cancer is estimated to increase more than fifteen-fold. The NAIIC observes that exposure data for plant workers, especially in the early period, was highly incomplete (NAIIC 2012).

2. No specific risk estimates were made for fetuses or breast-fed infants. In Chernobyl, twenty years of data suggest that the total long-term radiation dose should be projected to be three times the dose in the first year; in the WHO report it is assumed that the long-term dose in Fukushima will be only double the first-year dose for reasons that are not explained in the report.

References

Akiba, S. 2012. "Epidemiological Studies of Fukushima Residents Exposed to Ionising Radiation from the Fukushima Daiichi Nuclear Power Plant Prefecture—A Preliminary Review of Current Plans." *Journal of Radiological Protection*, vol. 32, no. 1 (March), pp. 1–10.

Bailly du Bois, P., P. Laguionie, D. Boust, I. Korsakissok, D. Didier, and B. Fievet. 2012. "Estimation of Marine Source-term Following Fukushima Dai-ichi Accident." *Journal of Environmental Radioactivity*, vol. 114 (December), pp. 2–9.

Buesseler, K. O. 2012. "Fishing for Answers off Fukushima." *Science*, vol. 338, no. 6106 (October), pp. 480–482.

———. 2013. "Fukushima Ocean Impacts." Presented at the Medical and Ecological Consequences of the Fukushima Nuclear Accident, New York Academy of Medicine, March 11–12, 2013, www.totalwebcasting.com.

Cardis, E., M. Vrijheid, M. Blettner, E. Gilbert, M. Hakama, C. Hill, G. Howe, and forty-five other authors. 2005. "Risk of Cancer After Low Doses of Ionising Radiation: Retrospective Cohort Study in 15 Countries." *British Medical Journal,* vol. 331, no. 7508 (July), pp. 77–83.

Cochran, T. B. 2011. *Statement on the Fukushima Nuclear Disaster and Its Implications for US Nuclear Power Reactors.* Testimony to US Senate Joint Hearings of Subcommittee on Clean Air and Nuclear Safety and Committee on Environment and Public Works, April 12, www.nrdc.org.

Committee on Fukushima Health Management Survey. 2013. Proceedings of the 11th Prefectural Oversight Committee Meeting for Fukushima Health Management Survey. www.fmu.ac.jp.

Doll, R., and R. Wakeford. 1997. "Risk of Childhood Cancer from Fetal Irradiation." *British Journal of Radiology,* vol. 70 (February), pp. 130–139.

Floyd, R. 2011. "Testimony Before Joint Standing Committee on Treaties, Canberra, 31 Oct 2011." www.aph.gov.au.

Fukushima Radiation and Health. 2013. "WBC (Whole Body Counter) Monitoring by Fukushima Prefectural Government." April 24, www.fmu.ac.jp.

GOJ (Government of Japan). 2013. "Mission to Japan. Comments by the State on the Report of the Special Rapporteur." Human Rights Council, UN General Assembly. A/HRC/23/41/Add.5/Rev.1, May 27.

Goto, Y. 2012. "High Leukemia Rate Noted Among Kids of 2 A-bomb Survivors." *Asahi Shimbun,* June 4, http://ajw.asahi.com.

Grover, A. 2012. "UN Special Rapporteur's Press Statement." Press release 12-058-E, November 26, http://unic.or.jp.

———. 2013. "Report of the Special Rapporteur on the Right of Everyone to the Enjoyment of the Highest Attainable Standard of Physical and Mental Health." Addendum. Mission to Japan (November 15–26, 2012). Advance unedited version. Human Rights Council, UN General Assembly. A/HRC/32/41/Add.3, May 2.

Hecht, G. 2013. "Nuclear Janitors: Contract Workers at the Fukushima Reactors and Beyond." *Asia-Pacific Journal: Japan Focus*, vol. 11, no. 2 (January 14). www.japanfocus.org.

IAEA (International Atomic Energy Agency). 2012. "IAEA Fukushima Daiichi Status Report." February 23, www.iaea.org.

ICRP (International Commission on Radiological Protection). 2009a. "ICRP Statement on Radon." November. ICRP Ref 00/902/09.

———. 2009b. "Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas After a Nuclear Accident or a Radiation Emergency." ICRP Publication 111. *Annals of the ICRP,* vol. 39, no. 3.

Jobin, P. 2011. "Dying for TEPCO? Fukushima's Nuclear Contract Workers." *Asia-Pacific Journal: Japan Focus,* vol. 9, no. 3 (May 2), www.japanfocus.org.

———. 2012. "Fukushima One Year On: Nuclear Workers and Citizens at Risk." *Asia-Pacific Journal: Japan Focus*, vol. 10, no. 2 (March 26), www.japanfocus.org.

Kodama, K., K. Ozasa, H. Katayama, R. E. Shore, and T. Okubo. 2012. "Radiation Effects on Cancer Risk in the Life Span Study Cohort." *Radiation Protection Dosimetry,* vol. 151, no. 4 (August), pp. 674–676.

Little, M. P., T. V. Azizova, D. Bazyka, et al. 2012. "Systematic Review and Meta-Analysis of Circulatory Disease from Exposure to Low-level Ionizing Radiation and Estimates of Potential Population Mortality Risks." *Environmental Health Perspectives,* vol. 120, no. 11 (November), pp. 1503–1511.

Madigan, D. J., Z. Baumann, and N. S. Fisher. 2012. "Pacific Bluefin Tuna Transport Fukushima-Derived Radionuclides from Japan to California." *Proceedings of the National Academy of Sciences,* May 29, www.ncbi.nlm.nih.gov.

Mathews, J. D., A. V. Forsythe, Z. Brady, M. W. Butler, S. K. Goergen, G. B. Byrnes, G. S. Giles, A. B. Wallace, P. R. Anderson, T. A. Guiver, P. McGale, T. M. Cain, J. G. Dowty, A. C. Bickerstaffe, and S. C. Darby. 2013. "Cancer Risk in 680,000 People Exposed to Computed Tomography Scans in Childhood or Adolescence: Data Linkage Study of 11 Million Australians." *British Medical Journal*, vol. 346 (May), f2360, www.ncbi.nlm.nih.gov.

NAIIC (National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission). 2012. "The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission." Tokyo: National Diet of Japan.

NAS (National Academy of Sciences), Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation. 2006. "Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII, Phase 2." Washington, DC: National Academy of Sciences.

NOAA (National Oceanic and Atmospheric Administration), National Geophysical Data Center. 2013. Significant Earthquake Database, www.ngdc.noaa.gov.

OHCHR (Office of the United Nations High Commissioner for Human Rights), World Health Organization. 2008. "The Right to Health." Factsheet No. 31. Geneva: OHCHR.

Ozasa, K., Y. Shimizu, A. Suyama, F. Kasagi, M. Soda, E. J. Grant, R. Sakata, H. Sugiyama, and K. Kodama. 2012. "Studies of the Mortality of Atomic Bomb Survivors, Report 14, 1950–2003: An Overview of Cancer and Non-Cancer Diseases." *Radiation Research,* vol. 177, no. 3 (March), pp. 229–243.

Park, Jeffrey. 2011. "Earthquake 9.0: What This Magnitude Might Mean for Japan's Future." *Bulletin of the Atomic Scientists*, March 16, http://thebulletin.org.

Pijpe, A., N. Andrieu, D. F. Easton, A. Kesminiene, E. Cardis, C. Nogues, et al. 2012. "Exposure to Diagnostic Radiation and Risk of Breast Cancer Among Carriers of BRCA1/2 Mutations: Retrospective Cohort Study (GENE-RAD-RISK)." *British Medical Journal,* vol. 345 (September), e5660.

Radiation Medical Science Center for the Fukushima Health Management Survey. 2013. "Basic Survey (Radiation Dose Estimates) Reported on June 5, 2013." Fukushima Health Management Survey, www.fmu.ac.jp.

Stohl, A., P. Seibert, G. Wotawa, D. Arnold, J. F. Burkhart, S. Eckhardt, C. Tapia, A. Vargas, and T. J. Yasunari. 2011. "Xenon-133 and Caesium-137 Releases into the Atmosphere from the Fukushima Dai-ichi Nuclear Power Plant: Determination of the Source Term, Atmospheric Dispersion, and Deposition." *Atmospheric Chemistry and Physics Discussions,* vol. 11, no. 10 (October), pp. 28319–28394, www.atmos-chem-phys-discuss.net.

United Nations Economic and Social Council (ECOSOC). 2000. "General Comment No. 14 (2000): The Right to the Highest Attainable Standard of Health (article 12 of the International Covenant on Economic, Social and Cultural Rights)." UN Document E/C, 12/2000/4, http://daccess-dds-ny.un.org/doc.

WHO (World Health Organization). 2009. *WHO Handbook on Indoor Radon: A Public Health Perspective*. Geneva: World Health Organization.

———. 2012a. *Preliminary Dose Estimation from the Nuclear Accident After the 2011 Great East Japan Earthquake and Tsunami*. Geneva: World Health Organization.

———. 2012b. "The Right to Health." Factsheet No. 323 (November). Geneva: World Health Organization.

———. 2013. "Health Risk Assessment from the Nuclear Accident After the 2011 Great East Japan Earthquake and Tsunami Based on a Preliminary Dose Estimation." Geneva: World Health Organization.

Yasumura S., M. Hosoya, S. Yamashita, K. Kamiya, M. Abe, M. Akashi, K. Kodama, and K. Ozasa for the Fukushima Health Management Survey Group. 2012. "Study Protocol for the Fukushima Health Management Survey." *Journal of Epidemiology*, vol. 22, no. 5 (August), pp. 375–383.