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Lessons from Fukushima

By Peter Prebble

As of mid-June 2012, only 2 nuclear reactors in all of Japan were operational.¹ The remaining 52 nuclear reactors in the world's third largest economy were shut down. In fact, for a six week period that began on May 5, 2012, Japan functioned without electricity from a single nuclear power plant.² It is not yet clear how many of the nuclear reactor shut-downs will be temporary and how many will become permanent. However, what has happened to date is unprecedented, since two years ago nuclear power accounted for 30% of Japan's electricity supply. If the majority of Japan's nuclear power stations remain closed, it will represent the biggest and fastest denuclearization anywhere in the world.

All nuclear power plants must periodically be shut off for refueling and regular maintenance. This is normally a routine event. However, in the wake of the March 2011 accident at the Fukushima Daiichi (FD) nuclear power plant, Japan has required nuclear reactors to pass new safety tests and has been seeking local government approval before restarting reactors. To date, despite the

national government's warnings about the need to start-up nuclear reactors to avoid potential power blackouts, only two reactors in the town of Oi, in western Japan, are running. Local citizen opposition has played an important role in keeping the rest shut down, and the consent of local governments for reactor start-up can no longer be counted on.³



Photo Credit: Greg Webb / IAEA⁴

These events reflect a significant shift in Japanese public opinion on nuclear energy policy since the accident at the Fukushima Daiichi nuclear power plant. Opinion polls taken subsequent to the accident indicate that a clear majority of Japanese citizens favour a greatly diminished role for nuclear power in

society.⁵ Although the current Prime Minister of Japan is pressing to open more of the shut-down reactors, he faces substantial opposition to his plans.

The people of Japan endured terrible suffering and loss of life as a result of the March 11, 2011 earthquake and tsunami. Tragically, more than 20,000 people are dead or missing in eastern Japan as a result of these events. In addition, Japanese citizens faced three nuclear reactor meltdowns at the FD power station, each with massive radiation releases of fission products that contaminated the air, the ocean, groundwater, soil and crops.⁶ The radionuclides released included radioactive iodine and cesium, and isotopes of strontium and plutonium.⁷ Radiation levels spiked so high that even the plant's off-site emergency response centre, located 5 kilometres from the reactors, had to be evacuated.⁸

The reactor accidents at Fukushima were triggered by a combination of the 9.0 magnitude earthquake and tsunami waves of up to 14 metres striking the facility.⁹ The operating nuclear reactors were all successfully shut down by automatic systems that had been installed for the purpose of detecting earthquakes.¹⁰ However, the cooling systems for the nuclear reactors failed, as a result of a loss of on-site and off-site electricity, and this quickly led to a series of hydrogen explosions on site¹¹ and the

melting down of the uranium fuel bundles inside each operating nuclear reactor.

Radioactive Contamination Over Land and Sea

One perspective on the severity of the Fukushima accident is provided by the fact that Japanese authorities have classified it as a Level 7 accident, the highest severity rating on the international Nuclear Event Scale.¹² The only other incident to receive such a rating is the April 1986 Chernobyl nuclear power plant disaster. Despite its severity, the radiation release from Fukushima was not as great as that from Chernobyl.¹³ This is because the Fukushima reactors had containment vessels which helped curtail radiation release; whereas, the Chernobyl reactor had no containment structure and nothing stopped the movement of radionuclides into the atmosphere.¹⁴

A second perspective on the severity of the Fukushima accident is provided by the results of seawater monitoring that was undertaken two weeks after the tsunami struck the power plant. In late March of 2011, monitoring done close to the FD plant recorded peak radioactive iodine levels at 7.5 million times above the legal limit. Monitoring stations located several hundred metres off the Japanese coastline showed radioactive iodine levels in seawater to be

approximately 4,000 times above the legal limit.¹⁵ Despite the enormous dilution factor provided by the ocean, and the dispersal effect of ocean currents, radioactive iodine contamination still exceeded Japanese regulatory limits 30 kilometres out to sea.¹⁶ It is clear from these numbers that the release of radioactive isotopes into the Pacific Ocean was immense. Slightly elevated levels of radioactivity were detected as far away as Europe, Iceland and North America.¹⁷

A third perspective on the scale of the accident is provided by the fact that radioactive fallout from the Fukushima accident spread to every one of Japan's 45 prefectures.¹⁸ Of particular concern is contamination by cesium-137, a radionuclide with a radioactive half-life of 30.1 years. Unless removed, it will remain in the top layer of soil for long periods of time and have a deleterious effect on food production, livestock and human health. Cesium 137 from the Fukushima reactors has particularly contaminated the soils in large areas of eastern and northeastern Japan, whereas western Japan was sheltered by mountain ranges.¹⁹

Fortunately, sampling work done by the Ministry of Science, in cooperation with universities and the Japan Atomic Energy Agency, shows that the 'most severe' category of cesium 137 contamination is not as geographically

extensive in Japan as it was in Belarus and the Ukraine, after the Chernobyl accident.²⁰ This likely reflects the fact that less radiation was released into the atmosphere at Fukushima than at Chernobyl. Moreover, unlike the landlocked Chernobyl site, the prevailing winds at the Fukushima site moved a large amount of radiation out to sea, sparing Japanese citizens an even greater tragedy.

The Danger of Nuclear Power And The Implications for Canada

The Fukushima accident has reinforced one of the important dangers of nuclear power, namely that even when a nuclear reactor is successfully shut down in an emergency situation, a major radiation release can still occur.²¹ That is because, after shutdown, nuclear reactors must be cooled for a long period of time. If electricity is not available to run the cooling system pumps, as was the case at Fukushima, the uranium fuel bundles can reach temperatures of over 2,800 degrees Centigrade and melt down, releasing a vast store of dangerous radionuclides.²²

The Fukushima accident has significant implications for Canada. The provinces of Ontario, New Brunswick and Quebec have nuclear reactors, and Fukushima is an important reminder of what can go wrong at a nuclear power plant. Moreover, the province of Saskatchewan

is a major supplier of uranium to Japan. In the case of the FD nuclear power plant, Cameco Corporation, a large uranium mining company in Saskatchewan, has been providing uranium to Tokyo Electric Power Company, the FD plant owner. The fission products from the splitting of that uranium are now presumably part of the radioactive contamination problem the Japanese are trying to clean up. Finally, Canada is struggling with issues surrounding nuclear waste disposal. As we shall see, the Fukushima accident illustrates how the waste materials in spent nuclear fuel bundles can become a major public health hazard.

Consequences of the Accident in Fukushima Prefecture and Beyond

Today, approximately 80,000 residents in 8 towns and villages around the Fukushima nuclear power station are still unable to return home.²³ Many may never be able to do so.²⁴ Their properties and neighbourhoods are simply too radioactive. They lie inside a 20 kilometre exclusion zone established by the national government. Rice farmers living in Fukushima prefecture have found themselves unable to sell their crop because of radioactive contamination.²⁵ Even school grounds 40-60 kilometres away from the plant have been significantly contaminated with long-lived radioactive particles. To facilitate school attendance in the months after the



Credit: F. Bale/Nature/MEXT²⁶

accident, the Japanese government relaxed radiation safety standards for children attending classes in Fukushima prefecture. Under the new standards school children can be exposed to radiation levels 20 times more than was previously permissible.²⁷

Perhaps most serious of all, very large numbers of Japanese citizens have been exposed to excessive amounts of ionizing radiation, a circumstance that is certain to lead to elevated rates of cancer in the years to come.²⁸ A comprehensive study of the accident's impact on health should come in May 2013 when a UN scientific committee is expected to publish its results.²⁹ The Japanese government has also launched a testing programme in Fukushima prefecture that includes 360,000 children up to 18 years of age.³⁰

Current On-Site Nuclear Dangers At Fukushima Daiichi

In December 2011 FD plant operators brought the reactors into a state referred to as a “cold shutdown”, a condition which signals that the release of radioactive materials from the primary containment vessels has been brought under control.³¹

However, since that time it has become clear that the problems at the FD power station itself are far from resolved. For example, the Japanese government is contending with serious difficulties at one of the plant’s nuclear waste storage pools. The spent fuel pool is now exposed to the outside environment after a hydrogen explosion blew off part of the reactor building.³² This means that any future radioactive releases could be dangerous over a wide area. The potential risks are illustrated by a Brookhaven National Laboratory (USA) report in 1997 that estimated that if a spent fuel pool in a boiling water reactor went dry and then caught on fire, it would kill at least 187,000 people.³³ The risks posed by the spent fuel pool, in the event of another earthquake, are so serious that dozens of non-profit groups across Japan are urging the United Nations to organize a security summit focussed on the FD nuclear fuel pool.³⁴

Moreover, cooling the stricken reactors at Fukushima still requires injecting thousands of litres of water into the reactors each day, and this process is generating tens of thousands of tonnes of contaminated water.³⁵ Finally, there is ongoing uncertainty about what is actually going on inside some of the nuclear reactors. For example, an internal investigation released by Tokyo Electric Power in March of 2012 found water levels in one of the stricken reactors to be much lower than previously thought, raising worries that it could heat up again.³⁶



*Photo Credit: Kim Kyung-hoon/Reuters*³⁷

The Cleanup and Decontamination Task Ahead

The actual cleanup of the FD nuclear power plant site will take several decades to complete.³⁸ The damage inside the reactor containment chambers is so severe that special decommissioning

equipment and technology will have to be developed to tolerate the high temperatures and harsh environment.³⁹ Present timelines for the clean-up process on the site are in the range of 30-40 years.⁴⁰ The total cost of the disaster is currently estimated at one hundred billion dollars.⁴¹

Tokyo Electric Power Corporation (TEPCO), the owner of the power station, faces claims totalling tens of billions of dollars.⁴² The Government of Japan has recently provided the company with a \$12.6 billion bailout package, and in return will acquire majority voting rights in TEPCO.⁴³ The government has signalled it will relinquish control of TEPCO once the company has sufficient credibility to raise funds again on the bond market.⁴⁴

The off-site decontamination task that lies ahead is enormous. To reach its target of halving radiation levels within two years, the Japanese government hopes to remove large quantities of contaminated soil. The agricultural ministry estimates that scraping 4cm of topsoil from contaminated farmland in Fukushima prefecture would fill 20 football stadiums. Some decontamination work has already begun, but storing the waste is problematic.⁴⁵

Nuclear Reactor Cancellations Around The World

The ramifications of the Fukushima accident extend well beyond Japan.

Many other countries are now following Japan's lead in winding down their nuclear power plants. For example, Germany shut down 8 of its nuclear reactors, following Fukushima, and plans to phase out all of its nuclear power plants by 2022.⁴⁶ Switzerland has cancelled all plans for buying new nuclear power plants. Italy voted in a referendum last year to reject nuclear power.⁴⁷ In the wake of the accident, Mexico dropped plans to build 10 reactors; Venezuela froze plans for nuclear projects and Kuwait pulled out of a contract to build 4 reactors.⁴⁸ In May of this year, Brazil shelved plans to build at least 4 new nuclear reactors.⁴⁹

Events That Almost Made Fukushima Far Worse

One of the important lessons from Fukushima is how much worse the consequences of the accident could have been. As mentioned above, Japan's citizens were spared the full effect of the radioactive releases. The prevailing winds and the fact that the FD plant is adjacent to the ocean meant that the majority of radionuclides were blown out to sea. In the case of cesium 137, for instance, almost 80% of the release is estimated to have ended up in the Pacific Ocean.⁵⁰ Another factor that prevented the accident from being more catastrophic is that three of the six nuclear reactors at the site were out of service at the time of the accident, since they had been taken

off-line for regularly scheduled maintenance.⁵¹ The three reactors that were operating all had uranium fuel meltdowns. It is logical to assume that other reactors at the site might also have had fuel meltdowns, had they been running at the time the earthquake and tsunami knocked out power.

Yet another factor that reduced the health impacts of the disaster was a courageous decision by the plant manager, Masao Yoshida, to continue using seawater to cool the reactors, even though he had been ordered by Tokyo Power Corporation not to do so.⁵² His quick thinking and courage prevented the reactor meltdowns from becoming even more severe. Moreover, staff at the power plant displayed great dedication and bravery in their efforts to restore some level of control at the site. They worked in darkness, in very dangerous conditions and without access to regular instrumentation and control systems.⁵³

Other actions by Tokyo Power Corporation underline how the crisis could have further deteriorated. Perhaps the most disturbing is the news that, three days into the nuclear crisis, the company's President requested permission from Japan's Prime Minister to withdraw his employees from the FD plant because of the dangers associated with remaining there.⁵⁴ Fortunately, the Prime Minister of Japan denied the request.⁵⁵ Had it been granted, it is highly

likely that Japan would have lost control of all the reactors on the site and their spent fuel bays. As a February 2012 U.K. *Guardian* editorial noted, site abandonment "could have unleashed a chain reaction of plant meltdowns that could have resulted in the evacuation of Tokyo."⁵⁶

In Japan Electricity Conservation Has Become A High Priority

In assessing the consequences of Fukushima, the real hope for the future lies in the energy alternatives Japanese people are now pursuing. Nuclear power provided 30% of the nation's electricity 15 months ago.⁵⁷ Today Japan is coping by reducing energy use and cutting peak demand for electricity, while spreading the electrical load more evenly throughout the week.⁵⁸ Japan is also launching feed-in-tariffs for renewable energy and investing in solar and wind technology. Last year, for example Japan installed 1,000 megawatts of solar photovoltaics, a modest but important beginning.⁵⁹ Moreover, Japan has excellent tidal and geothermal resources. In the case of geothermal, for example, there are thousands of hot springs in the country with great potential to provide hot water and heating services to local communities.⁶⁰

The citizens of Japan have begun the journey towards creating a more sustainable energy future for their

country. As a nation with a long history of innovation and engineering expertise, they are well equipped to set an example for many other countries in the world.

Concluding Comments

Here at home, a critical decision for Canadians is whether to continue on with nuclear power or to phase it out. The Fukushima accident reminds us that nuclear power technology presumes a society in which there are no unexpectedly complex disasters and no wars, and a society in which back-up sources of electricity are always at hand. Unfortunately, these pre-conditions cannot always be counted on, and when they are not available, nuclear reactors are a very unforgiving technology.

With the actions that are unfolding in both Japan and Germany, we are now seeing the third and fourth largest economies on our planet dramatically reducing their reliance on nuclear energy. Their example is yet another illustration of why, in my opinion, the time has come to halt the construction of new nuclear power stations and uranium mines in Canada. Existing nuclear power facilities in Canada should be subject to an orderly, carefully planned phase-out and should be replaced by large scale electricity conservation measures and the building of a renewable energy future for our country.

Peter Prebble has been involved in Saskatchewan's environmental movement for 35 years. He holds a Master's Degree in Sustainable Environmental Management and a Master's Degree in Education, both earned at the University of Saskatchewan. In addition, he holds a Bachelor's Degree in Business Administration from the University of Prince Edward Island, where he was awarded a Governor General's Gold Medal upon completion of his undergraduate work. Mr. Prebble was a Member of the Saskatchewan Legislature for 16 years. He held several Cabinet posts and also served as the Premier's Legislative Secretary for Renewable Energy Development and Conservation. He has also worked in many roles for the Saskatchewan Environmental Society, most recently serving as their Director of Energy and Water Policy.

References

¹ Japan OK's restart of first nuclear reactors since 2011 tsunami", *Associated Press*, June 16, 2012. Note: Of the 52 nuclear reactors that are shut down, only 48 now have the potential to operate. The remaining 4 are at the Fukushima-Daiichi nuclear power plant and are inoperable as a result of the accident there.

² Thousands march as Japan shuts off nuclear power" by Yuri Kageya, *Associated Press*, May 5, 2012 (<http://www.time.com/time/world/article/0.8599.21114038.00html>)

³ "Japanese energy policy stands at a crossroads" by Catherine Mitchell, Antony Froggatt and Shunsuke Managi, *The Guardian*, May 3, 2012.
"Thousands march as Japan shuts off nuclear power" by Yuri Kageya, *Associated Press*, May 5, 2012.

⁴ The photo shows IAEA fact-finding team leader Mike Weightman examining Reactor Unit 3 at the Fukushima Daiichi Nuclear Power Plant on 27 May 2011 to assess tsunami damage and study nuclear safety lessons that could be learned from the accident.

⁵ 71% against hastily starting Oi nuclear plant: Mainichi poll”, *The Mainichi*, June 4, 2012. The article reports on a poll taken between June 2nd and 4th, 2012 which indicates that 25% of respondents favour a complete ban on nuclear power, while 48% favour nuclear power making up 15% of electrical supply by 2030. The article also reports that only 23% of respondents favour an early restart of the Oi nuclear reactors; while 71% say the national government should not be rushing to restart the reactors.

“Fukushima protesters urge Japan to abandon nuclear power” by Justin McCurry, *The Guardian*, September 19, 2011. The article reports on a poll by Associated Press and a marketing research firm GFK. The poll indicated that 55% of Japanese want to see the number of nuclear reactors reduced, while 35% want to see the number kept the same.

⁶ *Fukushima Nuclear Accident Update Log*, International Atomic Energy Agency, March 24, 2011, p. 4. In the Fukushima and Ibaraki Prefectures, the IAEA reported that “of the 11 varieties of vegetables sampled from 18 to 22 March, iodine-131 and caesium-137 exceed limits for food and drink ingestion.” Levels of iodine and caesium were also exceeded in nearly all of the milk samples taken in the two Prefectures between March 16th and 21st. In addition “permissible levels of iodine-131 were exceeded in drinking water samples taken in the Fukushima and Ibaraki Prefectures and in Tokyo from 17 to 23 March.”

“Japan nuclear plant confirms meltdown of two more reactors” by Justin McCurry, *The Guardian*, May 24, 2011.

“Japan fears radioactive contamination of marine life”, by Ian Sample *The Guardian*, March 30, 2011.

“Fukushima: third worker death not related to radiation”, *The Guardian*, Oct 7, 2011. The article reports that a study has found radiation levels of 307,000 becquerels of cesium per kg of soil in soil samples taken in Fukushima city, well above the government-set legal limit of 10,000 becquerels per kg.

⁷ “Isotopic evidence of plutonium release into the environment from the Fukushima DNPP accident” by Zian Zheng, Keiko Tagami, Yoshito Watanabe, Shiego Uchida, Tatsuo Aono, Nobuyoshi Ishii, Satoshi Yoshida, Yoshihisa Kubota, Soichi Fuma and Sadao Ihara. *Scientific Reports* 2, Article No. 304, March 8, 2012.

“Plutonium detected at Fukushima”, *The Guardian*, March 29, 2011.

“Japan fears meltdown worse than first thought” Mark Wallacy, *Australian Broadcasting Corporation*, June 10, 2011. Wallacy notes an official report prepared for the United Nations by the Japanese government indicates that strontium 90, a bone seeker that can cause bone cancer and leukaemia, has been found as much as 60 kilometres away from the nuclear facility. Higher levels were found in Minamisoma, a city of 70,000.

E-mail from Dr. Gordon Edwards, May 28, 2011. Edwards explains that radioactive iodine concentrates in the thyroid gland and in milk. Radioactive cesium concentrates in blood and soft organs. Radioactive vapours condense and stick to soil, plants, animals, fish and inner organs, entering and concentrating in the food chain.

⁸ *Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company, Executive Summary of the Interim Report*, December 26, 2011, p. 3. The Committee notes that the off-site emergency response centre lost its functionality because it could not withstand elevated radiation levels, which the building structure was not designed to handle, and because “it was not assumed that nuclear disasters may strike simultaneously with outbreak of an earthquake.”

“FD: Inside the debacle” by Bill Powell and Hideko Takayama, *Fortune Magazine*, April 20, 2012.

⁹ *IAEA International Fact Finding Expert Mission of the Nuclear Accident Following the Great East Japan Earthquake and Tsunami*, May 24-June 1, 2011, Preliminary Summary, June 1, 2011, p. 1.

¹⁰ Ibid.

¹¹ “Isotopic evidence of plutonium release into the environment from the Fukushima DNPP accident” by Zian Zheng, Keiko Tagami, Yoshito Watanabe, Shiego Uchida, Tatsuo Aono, Nobuyoshi Ishii, Satoshi Yoshida, Yoshihisa Kubota, Soichi Fuma and Sadao Ihara. *Scientific Reports* 2, Article No. 304, March 8, 2012.

¹² *IAEA International Fact Finding Expert Mission of the Nuclear Accident Following the Great East Japan Earthquake and Tsunami*, May 24-June 1, 2011, Preliminary Summary, June 1, 2011, p. 2.

¹³ “Fallout forensics hike radiation toll: Global data on Fukushima challenge Japanese estimates” by Geoff Bumfiel, *Nature* 478, October 25, 2011, p. 435-36.

“Fukushima soil fallout far short of Chernobyl” by Jun Hongo, *The Japan Times*, March 15, 2012.

¹⁴ “How does Fukushima differ from Chernobyl”, BBC News Asia-Pacific, December 16, 2011.

¹⁵ “Fukushima radioactivity hit 7.5m times legal limit: by Jonathan Watts, *The Guardian*, April 5, 2011.

¹⁶ *Fukushima Nuclear Accident Update Log*, International Atomic Energy Agency, March 24, 2011, p. 4. Refer to section entitled: ‘Japanese Seawater Samples Show Signs Of Radioactive Materials’.

Note: In addition to radioactive iodine, large quantities of cesium, a much longer lived radioactive fission product, also polluted the ocean. Months after the accident, researchers from Tokyo University found high concentrations of cesium in plankton from Pacific Ocean waters south of the plant, raising worries that radiation will concentrate in fish and other marine species that feed on the plankton (Refer to: “Radioactive plankton found near Fukushima plant” by North Asia correspondent Mark Willacy, ABC News, October 15, 2011.)

¹⁷ Radiation from Japan reactor detected in B.C. seaweed, rainwater; no risk to humans” by Tracy Sherlock, *Vancouver Sun*, March 29, 2011.

“Elevated radiation levels in Ontario”, by Antonella Artuso and Jonathan Jenkins, *Toronto Star*, April 12, 2011.

“Radioactive particles detected in Europe”, ABC News (Australian Broadcasting Corporation), November 12, 2011.

¹⁸ “Cesium from Fukushima plant fell all over Japan” by Hiroshi Ishizuka, November 26, 2011, <http://aja.asahi.com/article0311disaster/fukushima/AJ201111260001> The article reports on the results of a survey by Japan’s Ministry of Education, Culture, Sports, Science and Technology.

¹⁹ “Cesium-137 deposition and contamination of Japanese soils due to the Fukushima nuclear accident “ by Teppei J. Yasunaria, Andreas Stohl, Ryugo S. Hayanoc, John F. Burkhardt, Sabine Eckhardt, and Tetsuzo Yasunarie, *Proceedings of the National Academy of Sciences*, November 14, 2011.

²⁰ “Fukushima soil fallout far short of Chernobyl” by Jun Hongo, *The Japan Times*, March 15, 2012. The article reports that at Chernobyl, a benchmark of 1.48 million becquerels of cesium per square metre was used to define the exclusion zone and these levels of contamination were found as far as 250 kilometres from the reactor site. In Japan, the site farthest from the Fukushima plant that was found to have these extremely high levels of contamination is the town of Namie. It is located just over 32 kilometres from the FD reactors.

²¹ IAEA International Fact Finding Expert Mission of the Nuclear Accident Following the Great East Japan Earthquake and Tsunami, May 24-June 1, 2011, Preliminary Summary, June 1, 2011, p. 1-2. The International Atomic Energy Agency team of experts concluded the operational units at FD nuclear power station and other nearby reactors were “successfully shutdown by the automatic systems installed as part of the design of the nuclear power plants to detect earthquakes.” Nevertheless “with no means to control or cool the reactor units...” they “quickly heated up due to usual reactor decay heating...” A series of explosions ensued and “...radiological contamination spread into the environment.”

²² E-mail from Dr. Gordon Edwards, Chairperson of the Canadian Coalition for Nuclear Responsibility. Dr. Edwards notes that the temperature rise is caused by “decay heat”, heat that results from radioactive decay. He states: “No one knows how to speed it up, slow it down, start it, or stop it.... And as long as that decay heat is being produced, it will drive the temperature up and up, unless the heat can be removed as rapidly as it is being produced. For that you need pumps, and for those you need power.” Edwards notes that the core meltdowns would take place at temperatures in excess of 2,800 degrees C (5,000 degrees F)

“Fukushima: The Crisis is Not Over”, June 2011 by Arnie Gundersen, Fairewinds Associates, Inc. Gundersen, a nuclear engineer, explains that the heat is produced by the radioactive byproducts of nuclear fission, such as cesium 137, strontium 90, and plutonium 239. Gundersen states “Unless the decay heat is removed as fast as it is produced, the temperature will continue to rise, eventually damaging the fuel and letting radioactive gases and vapors escape.”

E-mail from Dr. Gordon Edwards. Dr. Edwards points out that the principal cause of the meltdowns at the FD reactors - a complete blackout of electrical power, both onsite and offsite, for an extended period – can be created by many different circumstances and can potentially occur in any nuclear power plant in the world. He notes: “Such a situation could be caused by conventional sabotage or warfare, by a combination of a natural disaster and equipment failure, by a massive fire in the electrical wiring of a nuclear reactor, or just by accident.”

²³ Source: FD Status Report, *International Atomic Energy Agency*, April 27, 2012.

“Pupils return to school in Fukushima’s shadow: Japan has lifted evacuation orders for some villages just outside the 12-mile exclusion zone, but life is still dominated by radiation and the nuclear power plant” by Justin McCurry, *The Guardian*, April 16, 2012. The author reports that “in the coming weeks, 16,000 of the more than 100,000 displaced by the nuclear crisis could be able to return to their old neighbourhoods, although they will not be allowed to stay overnight until their homes have been decontaminated.”

The Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company stated at the time they submitted their interim report, in December 2011, that more than 110,000 people were still forced to live in evacuation circumstances. As noted above, since that time, a limited amount of resettlement has been possible. Refer to: *Executive Summary of the Interim Report of the Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company*, December 26, 2011, p. 2.

²⁴ “Fukushima disaster: residents may never return to radiation-hit homes” by Justin McCurry, *The Guardian*, August 22, 2011.

²⁵ “Pupils return to school in Fukushima’s shadow”, by Justin McCurry, *The Guardian*, April 16, 2012. The article reports the Japanese government’s lifting of evacuation orders in three communities outside the 12 mile no-go zone. In one of the villages, Kawauchi, local authorities have told farmers not to plant rice this year; radiation damage to the soil would render any crops unsellable.

“Tests find radiation in Fukushima rice” by Asian correspondent Mark Willacy, *ABC News*, November 18, 2011. The author indicates the tests were carried out on rice harvested 50 kilometres from the FD nuclear power plant. He states “officials from Fukushima prefecture have now all asked all rice farmers in the district to suspend shipments.”

“Japan bans Fukushima rice after radiation breaches limits” by Associated Press in Tokyo, *The Guardian*, November 17, 2011.

²⁶ The evacuation zones depicted were established in March of 2011. The 20km evacuation zone displayed in the chart remains in effect today. The 30km zone does not remain in effect today.

²⁷ “Japan’s Nuclear Catastrophe Leaves Little to Celebrate on Children’s Day” by Robert Alvarez, April 29, 2011. The author notes: “On April 19, the Japanese government sharply ramped up its radiation exposure limit to 2,000 millirem per year (20mSv/y) for schools and playgrounds in Fukushima prefecture. Japanese children are now permitted to be exposed to an hourly dose 165 times above normal background radiation and 133 times more than levels the U.S. Environmental Protection Agency allows for the American public.” He goes on to say this is the same level recommended by the International Commission on Radiation Protection for nuclear workers. He notes that experts consider children 10-20 times more vulnerable to contracting cancer from exposure to ionizing radiation than adults.

“Fukushima parents dish the dirt in protest over radiation levels” by Jonathan Watts, *The Guardian*, May 2, 2011. The article reports that the acceptable radiation safety level in schools has been increased from 1 millisievert to 20 millisieverts. It goes on to say: “It is estimated that 75% of Fukushima’s schools may have radiation levels above the old safety level of 1 millisievert”.

²⁸ “Fukushima residents urine now radioactive”, *The Japan Times*, June 27, 2011”. *The Japan Times* reported on radiation exposure of 15 residents in the village of Iitate and the town of Kawamata based on two rounds of sample tests taken in early and late May 2011 by doctors at the Watari Hospital in the city of Fukushima and by Nanao Kamada, professor emeritus of radiation biology at Hiroshima University. Both communities are 30-40 km from the Fukushima power plant. Accumulated external exposure during the two month period varied between 4.9 and 13.5 millisieverts. Internal exposure was also confirmed. Radioactive cesium was found both times in each resident tested. Professor Kamada is quoted as saying that ‘it will be difficult for people to continue living in these areas’.

“Fukushima nuclear plant may have suffered melt-through, Japan admits”, by Justin McCurry. *The Guardian*, June 8, 2011. The Guardian reports that as of late May 2011, about 7,800 workers took part in the struggle to stabilize the reactors at the Fukushima plant. Some may have been exposed to over 250 millisieverts of radiation.

“Fukushima residents plagued by health fears of nuclear threat in their midst” by Justin McCurry, *The Guardian*, March 9, 2012. The article reports on a study by Tetsuji Imanaka, an associate professor of nuclear engineering at the Kyoto University Research Reactor Institute, which found unusually high pockets of radiation in the village of Iitate, 39 kilometres from the Fukushima plant.

In the period before early April, 2011 alone, Japan’s Nuclear and Industrial Safety Agency announced between 10 and 17 million curies of radioactive materials were released to the atmosphere. (“Japan’s Nuclear Catastrophe Leaves Little to Celebrate on Children’s Day” by Robert Alvarez, April 29, 2011.) Radiation levels around the power station continued to increase during the month of April. Alvarez goes on to note that radiation measurements one meter above ground indicate that children at hundreds of schools received exposures 43-200 times above normal background levels.

“One year later, will Fukushima evacuees ever return home? By Andy Johnson, CTV News, March 11, 2012

²⁹ “Fukushima residents plagued by health fears of nuclear threat in their midst” by Justin McCurry, *The Guardian*, March 9, 2012.

³⁰ Ibid.

³¹ *FD Status Report*, International Atomic Energy Agency, April 27, 2012. In this report a “cold shutdown condition” is defined by TEPCO and the Nuclear Energy Response Headquarters as: “(1) Lowering the coolant water temperature to below 100 degrees centigrade while reducing the pressure inside the reactor vessels to the same as the outside air pressure, or 1 atmosphere (atm) and 2) Bringing release of radioactive materials from primary containment vessels under control and reducing the public radiation exposure by additional release (not to exceed 1 mSv/year at the site boundary as a target).”

³² “Nuke dangers nowhere near resolved: says ex-Prime Minister Kan’s crisis adviser” by Reiji Yoshida, *Japan Times*, February 8, 2012. The article quotes Hiroshi Tasaka, who has a doctorate in nuclear engineering and is a professor at Tama University and was a special advisor to the Prime Minister.

“No Nuclear Nirvana” by Robert Alvarez, *Huffington Post*, March 5, 2012 Alvarez states that the “structurally damaged spent fuel pool at Reactor No. 4 ...sits 100 feet above ground, exposed to the elements. Drainage of water from the pool resulting from another quake could trigger a catastrophic radiological fire involving about eight times more radioactive cesium than was released at Chernobyl.”

“Japan Admits Nuclear Plant Still Poses Dangers” by Hiroko Tabuchi, *New York Times*, March 29, 2012. According to the article: “The spent fuel rods stored at the No. 4 reactor pose a particular threat....because they lie unprotected outside the unit’s containment vessel. Tokyo Electric has been racing to fortify the crumpled outer shell of the reactor, and to keep the tank fed with water. But should a problem also arise with cooling the spent fuel, the plant could run the risk of another colossal radiation leak, experts say.” “The plant is still in a precarious state” said Mr. Kudo of Kyushu University. “Unfortunately, all we can do is to keep pumping water inside the reactors and hope we don’t have another big earthquake.”

³³ *United States Nuclear Regulatory Commission, Transcript of Proceedings*, October 7, 2011 “Meeting Between US. Nuclear Regulatory Commission and The Petitioner, Beyond Nuclear, Regarding 10 CFR2.206 Petition Request To Suspend General Electric MARK 1 Boiling Water Reactors Operating Licenses Due To Flawed Primary Containment And Unreliable Back-Up Electric Power Systems For Cooling Spent Fuel Pools”.

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<http://fukushima.greenaction-japan.org/2012/05/01>

“Urgent Request to UN Secretary General Ban Ki-moon”. This request notes that the Unit 4 spent nuclear fuel pool contains cesium 137 levels equivalent to 10 times the amount that was released at the time of the Chernobyl accident. The collapse of the pool, in the event of another earthquake, could have catastrophic consequences worldwide

³⁵ “Nuke dangers nowhere near resolved: says ex-Prime Minister Kan’s crisis adviser” by Reiji Yoshida, *Japan Times*, February 8, 2012 The article quotes Hiroshi Tasaka, who has a doctorate in nuclear engineering and is a professor at Tama University and was a special advisor to the Prime Minister. Unit 4 was offline when the disaster struck. Its fuel rods were in the pool outside the reactor and its coolant water fell dangerously low. The article says: “The ad hoc system for decontaminating the coolant water is nevertheless generating large amounts of highly contaminated waste every day. Making matters worse, the government doesn’t have any place to permanently store it”

E-mail from Dr. Gordon Edwards, February 29, 2012. Edwards notes: “Even now, and for some years to come, heat must be removed from the radioactive mass in the core of each reactor by flushing water through it at a tremendous rate...Cooling the core automatically flushes out those radioactive materials on an ongoing basis – and then you have enormous volumes of radioactively contaminated water that has to go somewhere.”

³⁶ “Japan Admits Nuclear Plant Still Poses Dangers” by Hiroko Tabuchi, *New York Times*, March 29, 2012. The author notes that water levels inside the core of reactor No. 2 came up to just 2 feet from the bottom of the reactor’s containment vessel, far below the 33 foot level estimated by officials in December 2011. Workers still pump about 9 tones of water an hour into the core to keep it cool. The author reports that radiation levels inside the containment vessel would kill a person in a matter of minutes. They are at 72 Sieverts.

³⁷ A child is tested last year for possible radiation exposure at an evacuation centre in Koriyama – about 70km (44 miles) from the Fukushima Daiichi nuclear reactor.

³⁸ “Fukushima nuclear plant could take 30 years to clean up” by Justin McCurry, *The Guardian*, October 31, 2011.

³⁹ “Fukushima reactor shows radiation levels much higher than thought”, by Associated Press. *The Guardian*, March 28, 2012.

⁴⁰ “The Fukushima nuclear plant’s slow recovery offers lessons to the U.S.” by Richard Schiffman, *The Guardian*, May 7, 2012.

⁴¹ “Fukushima owner saved from collapse by Japanese government”, by Justin McCurry, *The Guardian*, May 9, 2012.

⁴² Ibid

⁴³ “Japan to Nationalize Fukushima Utility (TEPCO)” by Hiroko Tabuchi, *New York Times*, May 9, 2012.

⁴⁴ Ibid.

⁴⁵ “Fukushima nuclear plant could take 30 years to clean up.” by Justin McCurry. *The Guardian*, October 31, 2011.

⁴⁶ “Germany votes to end nuclear power by 2022: fourth largest industrial nation set to replace nuclear with renewable energy”, *The Guardian*, June 30, 2011. The article is written by Associated Press. The article states the lower house of parliament voted 513 to 79 for the shutdown plan. Germany plans to double its share of energy from renewables to 35% by 2020.

⁴⁷ “Switzerland Decides on Nuclear Phase-Out” by James Kanter, *New York Times*, May 25, 2011. The author notes the last reactor in Switzerland will go offline by 2034. Approval for 3 new reactors is suspended. The five existing reactors will be allowed to continue operating, but will not be replaced at the end of their life span.

“What Italy’s nuclear referendum means for climate change: Voters overwhelmingly backed anti-nuclear campaigners’ demands to block any new atomic power in Italy”, *The Guardian*, June 15, 2011.

⁴⁸ “Dramatic fall in new nuclear power stations after Fukushima” by Fiona Harvey, John Vidal and Damian Carrington, *The Guardian*, March 8, 2012.

⁴⁹ “Brazil shelves plans to build new nuclear plants”, *Google News Service*, May 9, 2012. The article notes that Brazil currently has 2 nuclear reactors with a third under construction. Prior to the announcement, the Brazilian government had planned to construct between 4 and 8 nuclear reactors by 2030.

⁵⁰ A. Stohl et al. “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 Physics Discuss.net*, 11, 28319-28394.

⁵¹ “FD: Inside the debacle” by Bill Powell and Hideko Takayama, *Fortune Magazine*, April 20, 2012. Refer to the section of the article entitled ‘The Darkest Hours’.

⁵² In Nuclear Crisis, Crippling Mistrust” by Norimitsu Onishi and Martin Fackler, *The New York Times*, June 12, 2011.

FD: Inside the debacle” by Bill Powell and Hideko Takayama, *Fortune Magazine*, April 20, 2012. Refer to the section of the article entitled ‘A Tough Moment.’

⁵³ IAEA International Fact Finding Expert Mission of the Nuclear Accident Following the Great East Japan Earthquake and Tsunami, May 24-June 1, 2011, Preliminary Summary, June 1, 2011, p. 1-2.

⁵⁴ "In Nuclear Crisis, Crippling Mistrust" by Norimitsu Onishi and Martin Fackler, *The New York Times*, June 12, 2011.

⁵⁵ Ibid.

⁵⁶ "Japan's nuclear disaster: a long half-life", Editorial, *The Guardian*, February 28, 2012.

⁵⁷ "FD: Inside the debacle" by Bill Powell and Hideko Takayama, *Fortune Magazine*, April 20, 2012. The authors note that prior to the accident, nuclear power generated 30% of Japan's electricity. Japan is the world's third largest economy.

⁵⁸ "Japanese energy policy stands at a crossroads" by Catherine Mitchell, Antony Froggatt and Shunsuke Managi, *The Guardian*, May 3, 2012.

⁵⁹ Ibid.

⁶⁰ "Japan rethinks its nuclear mindset" by David Suzuki, *The Globe and Mail*, February 17, 2012.