Fukushima Burning: Anatomy of a Nuclear Disaster□□福島炎上—核災害の構造 •Japanese text available. Updated

Asia-Pacific Journal Feature

Between 2012 and 2014 we posted a number of articles on contemporary affairs without giving them volume and issue numbers or dates. Often the date can be determined from internal evidence in the article, but sometimes not. We have decided retrospectively to list all of them as Volume 10, Issue 54 with a date of 2012 with the understanding that all were published between 2012 and 2014.

The May/June edition of Australian magazine Physician Life features a lengthy report on the Fukushima crisis by Melbourne-based nuclear radiologist Dr. Peter Karamoskos.

Update: June 11, 2011 ABC broadcast YouTube is available.

A Japanese translation is available here.

The issue is available in full online.

In the piece, Karamoskos poses and answers key questions for understanding what has taken place at Fukushima and what the likely public health effects will be.

What happens when a nuclear reactor overheats?

When nuclear cores overheat due to a lack of water coolant, they ultimately melt. Remaining water quickly turns to steam preventing replenishment of the water and endangering the integrity of the pressure vessel. Furthermore, the reactor pressure vessel may also melt leaking the melted fuel which may escape into the environment if the primary and secondary containment structures (concrete) have been damaged. Spent fuel is kept at around 25 degrees in cooling ponds for a few decades. The water must be continually replenished to maintain this temperature. If there is a loss of water or a failure of replenishment, the spent fuel will overheat and catch fire, releasing its radiotoxic contents. Note that the longer fuel is irradiated in the reactor core, the more radioactive it becomes due to the build-up of fission by-products which also contaminate the fuel limiting its usable life. Only about 1-2% of the uranium in fuel rods is actually used up in a reactor. It is these fission by-products that pose the greatest immediate danger if released into the environment.

Radioactive fallout and its health effects

Radioactive fallout from a nuclear reactor can be considered in two groups: isotopes of the noble gases (xenon, krypton-133) are radioactive elements with a very low chemical reactivity, relatively short half-lives, are not

retained by the body and they remain and become dispersed in the air without ground deposition. Hence they have limited adverse health potential. The second and more dangerous radioactive fallout group is represented by mainly the radioactive isotopes of iodine, cesium, and tellurium. These elements form fine suspended particles in the air (aerosols), which due to their weight will gradually end up falling on the ground when released into the air, contaminating all vegetation, clothing and any other surfaces including water sources. Those that pose the greatest health threat are Cesium-137 (half-life 30 years) and Iodine-131 (half-life 8 days). Iodine-131 is a beta emitter and is absorbed into the blood stream through inhalation and ingestion and concentrated by the thyroid gland where it is highly carcinogenic, predominantly in young people under 18 years of age. Cesium is a gamma and beta emitter. It is also absorbed by the body through the respiratory and gastrointestinal tracts and subsequently into the bloodstream and deposited throughout the body. Cesium takes between 10 days and 100 days for half of it to be excreted from the body so there is significant hazard once it is absorbed. Unlike I-131 therefore which loses most of its potential for harm in a few months, cesium remains hazardous in the environment for several hundred years.

So how much radioactivity was emitted and how does it compare to Chernobyl?

The spread of airborne contamination is unlikely to be evenly distributed due to many variables including the prevailing winds, the altitude the contamination reaches before dispersion and the time period of release. Thus, although we speak of radial zones from the plant, the shape of the fallout most likely will represent a plume rather than a concentric disc. Furthermore, the prevailing jet stream is towards the United States west coast which is likely to have higher levels of contamination (but still very minimal at that distance) than, say, northern Canada which is closer to Japan. Contamination is likely to spread throughout the northern hemisphere and indeed trace amounts have already been detected from nearly all monitoring sites in that hemisphere. There is effectively an 'air curtain' at the Equator that prevents contamination from reaching the southern hemisphere. Shortly after the nuclear plant explosions, a 20km exclusion zone was established and residents between 20 and 30km were advised to remain indoors. The IAEA and US NRC suggested this was inadequate and advised an 80km exclusion zone. Utilizing CTBT monitoring data, the Austrian Central Institute for Meteorology and Geodynamics calculated that in the first three days, the activity of I-131 emitted was 30% and Cesium-137 20-60% of the entire Chernobyl emissions of these isotopes. Although Chernobyl emitted vastly more fallout than Fukushima has to date, it was the I-131 and Ce-137 that accounted for most of the terrestrial human and environmental hazard, and these are the main Fukushima fallout components. Also, the Fukushima plant has around 1700 tonnes of fresh and used nuclear fuel on site with an unknown amount having been damaged, whereas the Chernobyl reactor had only 180 tonnes. As far as human health is concerned comparisons therefore between Chernobyl and Fukushima disasters are valid.

Emissions have continued since then, albeit at a lesser rate than initially was the case. Note, however, that there has also been extensive contamination of the sea off the coast of Fukushima as contaminated seawater runoff from the plant used to cool it continues unabated at a rate of 7,000 tonnes per day. Concentrations of radioactive iodine were measured at over 4,300 times the legal limit.

Measures to intentionally dump the contaminated seawater build-up into the sea are being considered. Contamination of the seawater will compromise the fish stocks along the local coast for some time and has destroyed any remnants of the fishing industry that were not wiped out by the tsunami.

France's Institute for Radiological Protection and Nuclear Safety (IRSN) has estimated that within 20km of the plant the levels of contamination will exceed that of Chernobyl, and there will be "a strongly contaminated zone, extending to 60km around Fukushima in which there will be "measurable impacts but not dramatic impacts" although the contamination will be less than the comparable area around Chernobyl. Beyond this zone contamination will be measurable as far as 250km but with health impacts not able to be measured.

The more extensive evacuation zone advised by the IAEA (but ignored by the Japanese authorities) was vindicated, as later monitoring showed hot spots of contamination as far as 43km from the plant with levels of activity comparable to those areas which were mandatory evacuation zones at Chernobyl. Ionising radiation (IR) imparts its deleterious health effects through two mechanisms: transference of its energy to atoms in biological tissue which then becomes electrically charged leading to the formation of free radicals which then damage the cell's genetic blueprint (DNA) leading to genetic mutations; and direct DNA disruption along the track as ionising radiation traverses through the cell's nucleus. This then predisposes to the initiation of cancer when the regulatory mechanisms of the cell fail. Cancer may not appear for 10- 50 (or more) years (latency), although can be as short as 5 years for leukemia. Ionising radiation is classified as a Class 1 carcinogen by the International

Agency for Research in Cancer of the World Health Organisation, the highest classification consistent with certainty of its carcinogenicity.

Two types of IR health effects are recognized. The severity of deterministic effects is directly proportional to the absorbed radiation dose. These include skin damage and blood disorders due to bone marrow effects. The higher the dose, the worse, for example is the skin radiation burn. These have a threshold below which they do not occur, although this may vary between individuals. This threshold is around 100) millisieverts (mSv) at which point blood production begins to be impaired. Deterministic effects which exceed around 1000mSv induce acute radiation sickness with vomiting, diarrhea, and shedding of mucosal linings of the gastrointestinal and respiratory tracts, bone marrow suppression and sterility. Once the dose exceeds more than 3000-5000 mSv, death is likely in a matter of days to weeks. Stochastic effects are 'probabilistic' in nature. In other words, the higher the dose the greater the chance of them occurring, however, once they occur their severity is the same irrespective of the original dose. The main stochastic effect is cancer. The lower the dose of IR, the lower the chance of contracting cancer, however the type and eventual outcome of the cancer is independent of current risk coefficients for the development of cancer are approximately 8% per 1000 mSv (ie. 1 in 12 chance) and 5% for cancer fatality (1:20). The US National Academy of Sciences reviewed the effects of low level ionising radiation (defined as less than 100 mSv) in their seminal report and concluded that: "... there is a linear dose-response relationship between exposure to ionizing radiation and the development of solid cancers in humans. It is unlikely that there is a threshold below which cancers are not induced." Emergency workers at the plant are likely to developed deterministic effects as their upper allowable occupational doses have

been increased to 250 mSv (from the 100mSv total dose over five years allowable. and the lmSv per annum allowable dose to the public). One incident induced radiation burns to two emergency workers' legs from stepping in highly radioactive water in reactor 2, with a calculated total dose of 180 mSv from this one incident. In order to limit occupational doses workers have been recruited from a 600 person pool of workers on a rotating basis, and recruitment from overseas has now become necessary to avoid exceeding the revised occupational dose limits. It is highly likely that some of these workers will die of their exposures from the induction of cancer. No cases of acute radiation sickness have been reported to date.

The longer term stochastic effects will be much harder to define given the relatively high background incidence of cancer and the long latency period for its appearance. The prompt evacuation of people from the immediate surrounding environment, notwithstanding the insufficient exclusion zone, and offshore wind on the days of maximum fallout, will have minimized these effects. Furthermore, the administration of stable iodine to block thyroid uptake of I-131 in sufficiently exposed young people will also have significantly decreased the development of thyroid cancer. Even though risk models of cancer induction can be used to predict the likely cancers over the next six decades, it is possible that we will never know the true number of actual excess cancers in the general population due to inherent statistical limitations and large uncertainties, even several decades after the event. This is particularly so at very low doses. The only exception to this will be excess thyroid cancers as this is a rare malignancy and hence is easily statistically detected.

How long will it take to resolve the crisis?

It all depends on what we mean by "resolve the crisis." The Japanese government has set a target of "several months" to stop the continuing atmospheric, sea and ground emissions from the plant. Note that this is a desired outcome, not necessarily the likely outcome. It is conceivable that more drastic measures need to be adopted including burying the entire plant under a concrete sarcophagus which alone is estimated will cost upwards of $12bn. Of course, the entire plant will need to be written off as even reactors 5 & 6 which were not damaged are too heavily contaminated. Cleaning up radioactive sites is massively costly, time consuming and dangerous. If the plant is able to be brought under control, it will take more than 30 years to decommission the reactors and decontaminate the site and will cost "more than 12 billion dollars." Of course, that is not the upper limit of liability for the beleaguered Japanese taxpayer Bank of America-Merrill Lynch has estimated an upper bound of $130bn for the Fukushima disaster alone in liabilities and economic losses. The decommissioning effort alone will likely bankrupt the operator TEPCO resulting in a knock-on massive liability for Japanese taxpayers. Unlike the case with all nuclear power generated around the world, where operators refuse to generate electricity unless most of their liabilities are capped in the event of a major accident, the 1961 Act on Compensation for Nuclear Damage places no cap on damages. However, if the company is bankrupted, this liability transfers to the taxpayers. After this disaster, the Japanese tax-payers will realise that it is they, not the nuclear power companies, who need protection.