*[Disclaimer: I work in the nuclear industry! But fear not, in this article I am going to do something incredible: try to rely on data rather than my opinions.]*

Let your mind slip back to 2011. There was this *huge* earthquake off the coast of Japan [2]. Likely, you’ll remember it as being the “Fukushima” earthquake, because of the damage to the Fukushima Daiichi Nuclear Power Plant (<https://en.wikipedia.org/wiki/Fukushima_Daiichi_nuclear_disaster>), and the media-coverage frenzy that followed. In Japan, the event is known as the 2011 Tōhoku (TOH-ho-ku) earthquake. It was the most powerful ever recorded in Japan, and the fourth most powerful earthquake in the world since modern record-keeping began in 1900 [3]. Sounds strong but, if you’re like me, you’ll prefer an absolute over a relative number. I recommend reading the first few sections of the Wikipedia entry (https://en.wikipedia.org/wiki/2011\_T%C5%8Dhoku\_earthquake\_and\_tsunami) yourself (yeah, I use Wikipedia, and so should you – more on that in a future blog post!), but here I have reproduced some of the most interesting figures, with the caveat that many of them are from “media” sources, rather than scientific journals or official government statistics:

The force of the earthquake *moved* Honshu, the main island of Japan, 2.4m to the east [4]. The tsunami waves were 40.5m high [5], that’s the same as a thirteen story building. In places the waves travelled 10km inland, or the distance from Canary Wharf to Hyde Park (if you’re familiar with London) [6]. Not impressed? Well, the effects of the earthquake were not limited to Japan. It is estimated that the earthquake *shifted the Earth on its axis by 10 to 25cm* [7]. Yep, you read that right. And if the Tōhoku earthquake seems to you like it happened only yesterday, maybe that’s because the quake might have *increased the Earth’s rotational speed by 1.8µs per day* [8]!

Whilst I cannot vouch for the accuracy of the above numbers, sadly we do know that the tremors and ensuing tsunami killed at least 15,984 [9] people, with many more missing, presumed dead. Over a *million* buildings were damaged or destroyed [10]. The World Bank estimated the cost of recovery and reconstruction to be US$235 billion, making it the *costliest natural disaster in history* [11][12].

I’m sorry if it feels like I’m labouring the point – and there is one coming, I promise – but it’s important to remember just how powerful the 2011 Tōhoku earthquake was before we get to what happened at the Fukushima Daiichi plant.

I’m not going to give the blow-by-blow Fukushima story – you can read the Diet (parliament) of Japan’s produced an official report here (<http://large.stanford.edu/courses/2013/ph241/mori1/docs/NAIIC_report_hi_res10.pdf>). The International Atomic Energy Agency (IAEA) report is probably the most authoritative and informative, and anything I discuss below related to the accident is taken from their work. If you don’t have hours to burn, the Encyclopaedia Britannica (yes, they do still exist) summarised the incident succinctly here (<https://www.britannica.com/event/Fukushima-accident>).

Contrary to what you may assume, there is no evidence of damage to the main safety systems of the Fukushima Daiichi plants (there were three reactors involved) from the earthquake itself (i.e. from ground vibrations). The problem lay in the plant operators’ underestimation of the likelihood of large tsunamis and the damage they might cause. Tsunami flooding caused the Fukushima plants to lose electricity supply to vital systems required to cool nuclear fuel that remains hot (due to radioactive decay products https://en.wikipedia.org/wiki/Decay\_heat) even after the reactor has been shut down.

TEPCO, the operator of the plants, made valiant efforts to cool the reactor cores as well as what are known as the Spent Fuel Pools (a kind of giant swimming pool where old fuel is stored until it has cooled down). They also made a series of well-documented mistakes, exacerbated by indecision and unclear division of responsibility between it, the nuclear regulator and the government. The result was a nuclear operator’s worst possible day at the office: some of the nuclear fuel got so hot it melted through its protective containment. You’ve probably heard of this event before, if only in Hollywood sci-fi: a core meltdown. Eventually, some fraction of this leaked fuel made it into the air and sea.

Bad. But *how* bad? Before we get to that, this is in no way intended as an apology for mistakes made by the Fukushima Daiichi designers, operators or anyone else, nor do I wish to belittle the real human tragedy of mass evacuation of areas around the Fukushima plant following the accident. I only mean to highlight the real-world *data* from the accident. Quoting naked statistics may seem hard and cold for what is clearly an emotive topic, but I would argue that it’s the only way for us to bring together points-of-view which seem irreconcilable on first impressions.

Back to that question: how bad was the Fukushima nuclear accident? By official measures, it was the second-worst accident after Chernobyl, rated 7 on the INES scale (http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-accident.aspx) (the most severe level). Despite that the United Nations investigations found that no “early-induced health effects were observed among workers or members of the public” [14, pg13]: this means no one got ill from radiation in the immediate aftermath of the nuclear accident. And what about the long term effects, such as cancer risk? The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reported to the United Nations General Assembly that: “no discernible increased incidence of radiation-related health effects are expected among exposed members of the public and their descendants” [14, pg13]:, i.e. we don’t think that there will be any additional cancers amongst those who lived in and around the Fukushima plants due to the accident. The IAEA did conclude that *plant workers* would have an increased risk in cancer, but that this increase would be so small that we won’t be able to confirm it even exists [14, pg13].

How can this be? you may ask. If you watched the news you might have convinced yourself that fish would be growing third eyes (this only happens on The Simpsons, by the way) and children would be born with abnormalities for years to come. Yet this is not the case. Even the second-worst accident (and the worst accident in a developed nation) will have no discernible negative health effects on the workers or public (Note that some workers did die during the accident due to a related hydrogen explosion, but I am following the typical, if irrational, approach of treating deaths from conventional hazards differently to those from nuclear effects).

You see, the amount of radiation picked up by workers and the public were not so large when compared to other sources of radiation, both natural and man-made, to which we are exposed *every single day*. The typical dose over two weeks for people within the Fukushima exclusion zone was 1 *millisievert*, or 1 mSv. Don’t worry if you don’t know what that is, just know that the radiation most of us pick up *every year* from the rocks, soil, buildings and roads around us, from the food we eat (bananas are particularly radioactive https://en.wikipedia.org/wiki/Banana\_equivalent\_dose) and the air we breathe, and from medical scans such as x-rays, is around 4 mSv. One particular monitoring station close to Fukushima recorded higher doses of around 40 mSv. This 40 mSv value is still within the typically allowed dose for a person who works with radiation as part of their job such as a radiologist, nuclear plant worker, or, surprisingly, an airline pilot (see below) i.e. it’s a dose that will not lead to an increased risk of cancer. So, the radiation that leaked during the Fukushima accident was a risk to the public (and was preventable), but it hasn’t (and probably won’t) make anyone ill. Now remember, this accident happened because of the *massive* Tohoku earthquake, it affected some of the oldest (i.e. least resilient) nuclear plants in the world, whose sea defences were inadequate, yet it didn’t lead to nuclear Armageddon. A brilliantly-visual tool to get your head around radiation doses is provided by the online nerd comic xkcd (<https://xkcd.com/radiation/>), including doses related to the Fukushima accident.

Understanding how low the human doses were from the second-worst civil nuclear accident, you can begin to see how even living alongside a nuclear power plant for your whole life poses negligible risk to your health; visit a nuclear plant in the UK and you’ll find commercial farms right next-door, safely growing food for our consumption. Many people think that “radiation” is being constantly exhausted by nuclear power plants: this is not the case. No measurable radiation should be escaping to the environment. And those big towers emitting white smoke? That’s just pure, ol’ H2O – coolant steam that has not come into contact with the reactor or fuel (note that the UK mostly uses seawater instead of cooling towers).

Again, without getting into the details of exactly how and why there was a mass evacuation of people from around the Fukushima area, nor why the evacuation lasted so long, it is worth considering some of the irrational behaviour witnessed during and following the accident: some people living *far* outside the zone of influence of any radioactive release, such as in Tokyo, took flights out of the country to escape the perceived risk of contamination. Every time you take a flight, you leave behind much of the protection our atmosphere affords you at sea level and expose yourself to radiation from space. As xkcd shows (<https://xkcd.com/radiation/>), someone on a flight out of Tokyo to escape perceived radiation risk might get a 40µSv dose, which is already almost as much as if you had camped out at Fukushima town hall for the whole event (100µSv)! But not to worry: the dose from a single flight is not a risk to your health, but airline pilots and crew must monitor their yearly dose to ensure they are within safe limits. Unfortunately, we are not generally very informed about how radiation is a natural phenomenon, how we’re subjected to it *constantly* and how small doses have no demonstrable link to illnesses such as cancer.

Surprisingly, it is the way in which the Fukushima evacuation was managed that caused the most damage: around 1000 premature deaths are thought to have occurred as a result of the extended evacuation due to factors such as fatigue, trauma, people’s fear that they’d received a fatal dose of radiation and restricted access to medical care at their evacuation shelter. 90% of the deaths were in persons over the age of 66 (<http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-accident.aspx>). It’s clear that the main tragedy in the whole Fukushima disaster was maintaining the evacuation beyond a few precautionary days. Put another way, the greatest damage came not from any radiation leak but from the misunderstanding of what the consequences of such a leak are for us human beings.

This is a common theme with nuclear energy: our fear of nuclear radiation is disproportionate to any real health risk. This is an idea that most find difficult to accept, that raises the hackles of many a Greenpeace employee and invites derision from the more sensational elements of the media. Even the usually balanced outlets such as the BBC seem to find it difficult to turn off their emotional brain and simply report the facts when it comes to nuclear. This probably isn’t helped by science-trained staff being outvoted by those trained in the arts and humanities who are less accustomed to handling statistics.

Following the Tohoku earthquake a lot of media focus was on the troubled nuclear power plants. Close to no mention was made of other large industrial complexes that were damaged by the quake and tsunami. I know that several large petrochemical works suffered large fires following the earthquake, but the information available, at least in English, is sparse. I found this video (<http://www.telegraph.co.uk/news/worldnews/asia/japan/8375497/Japan-earthquake-causes-oil-refinery-inferno.html>), this image (<https://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami#/media/File:SH-60B_helicopter_flies_over_Sendai.jpg>) and a couple of lines on the earthquake Wikipedia page (<https://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami#Oil,_gas_and_coal>). It’s highly probably that carcinogenic compounds (see these UK government guidelines (https://www.gov.uk/government/uploads/system/uploads/attachment\_data/file/316535/benzoapyrene\_BaP\_polycyclic\_aromatic\_hydrocarbons\_PAH\_guidance.pdf) and this scientific paper about how such compounds can accumulate in marine animals (https://www.ncbi.nlm.nih.gov/pubmed/7501868)) were released in leaks and fires at these petrochemical works, yet no one seemed in the least bit interested because….something something nuclear is different….

In a way they’re right: nuclear *is* different. But not in the way you might think:

Unlike fossil fuels such as gas and coal, nuclear is a source of low-carbon energy in a world where rising CO2 levels threaten our ecosystems. And unlike other low-carbon sources such as solar and wind, nuclear energy is high-intensity (low land use) and high-availability (whatever the weather). In a world with a growing population and ever-shrinking wilderness, do we really want to convert vast tracts of farmland or nature reserves into sprawling solar farms? Is it right to destroy natural water courses with dams for hydro energy? Perhaps it *is* the right thing to do, but I have not yet seen the arguments to support this idea, nor has there been the proper public discussion. With current (and this could change – look at what Tesla is doing <https://www.tesla.com/en_GB/utilities>) energy storage technology, an electricity grid supported entirely by wind and solar is also not feasible because the wind doesn’t always blow and the sun doesn’t always shine.

The cost of nuclear new build compared to renewable new build is too complex to cover in this article, but existing nuclear plants are a cheap source of low-carbon electricity. No matter what you think about new nuclear plants, if you’re really serious about meeting the threats of climate change, air pollution and habitat destruction, you should at least support the continual operation of existing nuclear plants so long as it is safe to do so.

Unfortunately, in many parts of the world this is not happening. Germany has been on the path towards phasing out nuclear for a while now, but decided to accelerate the closing down of existing nuclear plants following the Fukushima accidents. The current French government seems set to do the same. Germany’s decision to switch off nuclear has led to its continuing dependence on coal whilst other European countries such as the UK have all but phased it out. This has been terrible for CO2 emissions (https://www.parliament.uk/documents/post/postpn\_383-carbon-footprint-electricity-generation.pdf), air pollution deaths from respiratory illnesses (including cancer) (https://www.forbes.com/sites/jamesconca/2012/06/10/energys-deathprint-a-price-always-paid/#6e5a57bf709b), habitat destruction (http://www.dw.com/en/clash-in-german-forest-as-red-line-is-crossed/a-36606405), and, ironically, radiation emissions (<https://www.scientificamerican.com/article/coal-ash-is-more-radioactive-than-nuclear-waste/>) (from coal ash)!

If you take anything away from reading this article, let it be this: nuclear, like all other energy sources, has its pros and cons. These pros and cons should be weighed fairly and objectively, and without treating nuclear as something evil because of the industry’s failure to break the historical link to nuclear weapons. On the contrary, civil nuclear energy has provided the cheap energy our economies needed to become the prosperous societies we live in today, with a minimal contribution to climate change and illness in humans.

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