NUCLEAR POWER'S FATAL FLAWS:
THE REAL LESSONS OF FUKUSHIMA

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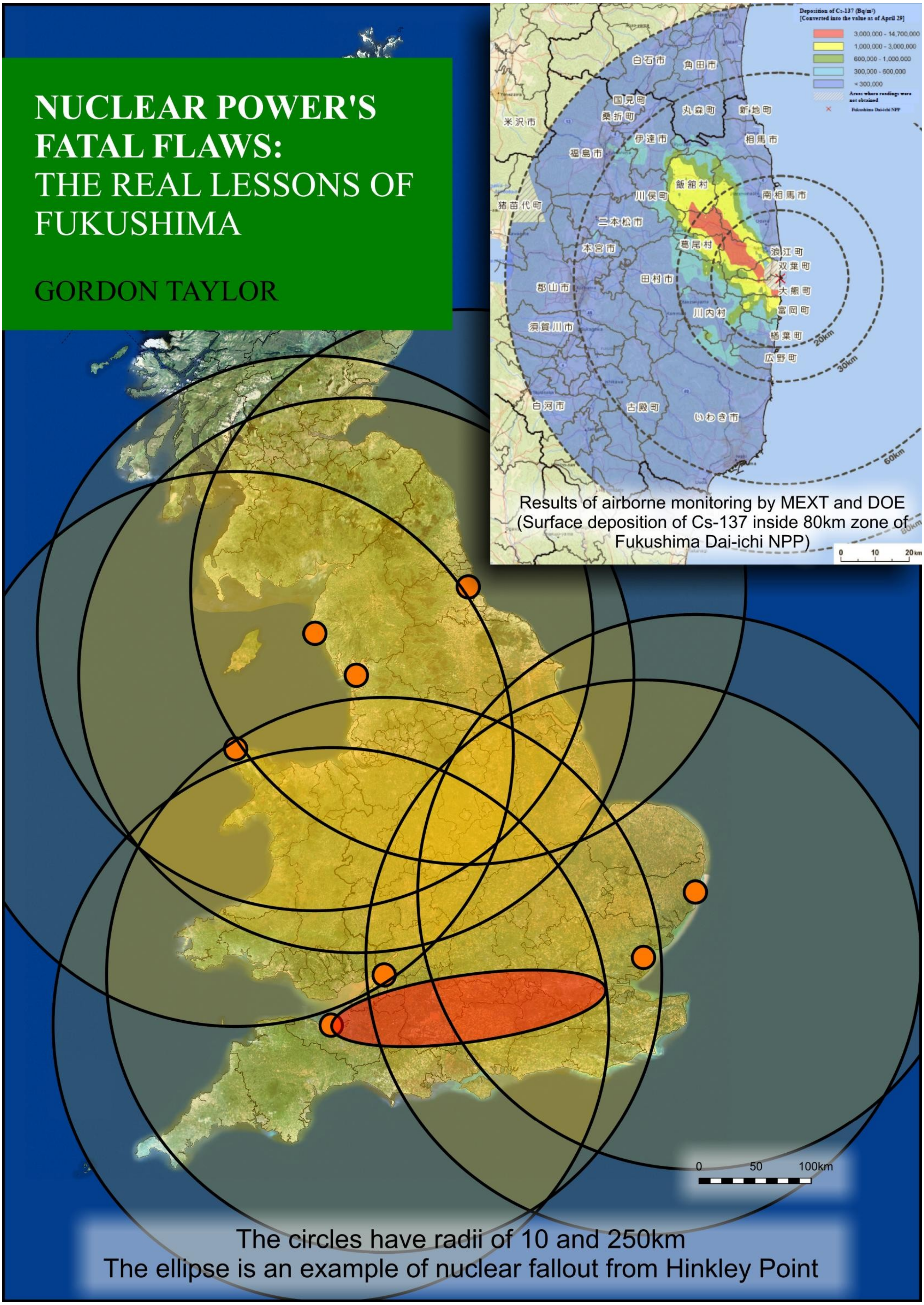


The circles have radii of 10 and 250km
The ellipse is an example of nuclear fallout from Hinkley Point

Summary

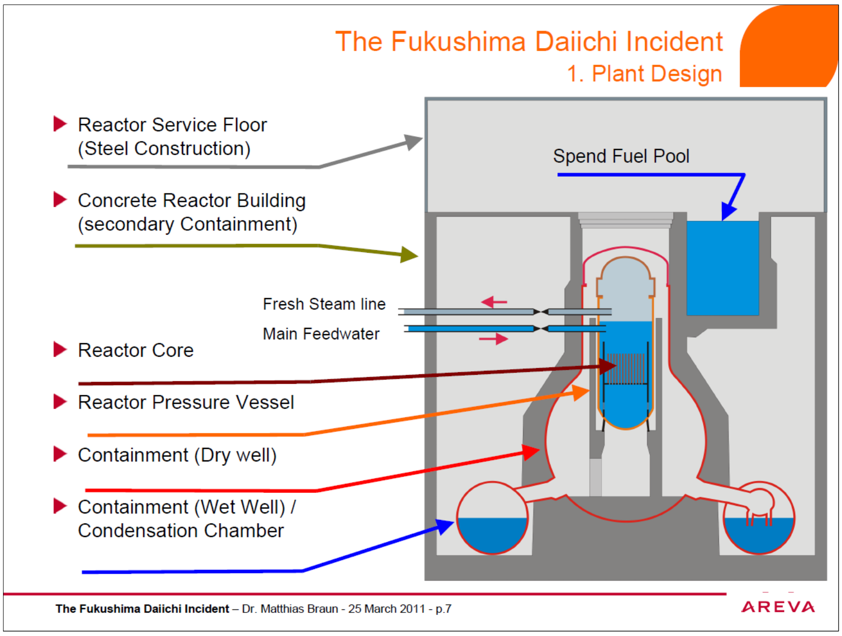
The UK government insists that nuclear power is necessary 'to keep the lights on' but it ignores six fatal flaws, with the first being fundamental nuclear physics that leads on to the other five. Once self-sustaining nuclear fission, or criticality, has been achieved, all nuclear fuel continues to release decay heat after shut-down. This is largely from the short-lived elements produced by the fission process. Unless this heat is removed continuously by cooling, the containments, the physical barriers between the reactor core and the environment, can fail, leading to major releases of radioactive fission products. These can be carried hundreds of kilometres, falling to land at concentrations that have health effects on humans and livestock. As well as injuries and prompt deaths within a month and latent deaths thereafter, the radioactivity can cause cell mutations, leading to genetic damage, manifest in all later generations. Such horrendous consequences necessitate continuous readiness for nuclear disasters. This requires radiation monitoring, analysis, and communication with the public over the entire potential fallout area around each nuclear power plant, together with published plans for their evacuation. These plans must be designed for worst case releases that are about one hundred times those from Chernobyl and Fukushima. Probabilities are irrelevant, since logic and experience shows that if a disaster is physically possible, it will happen. This was recognised from the beginning of civil nuclear power by the worldwide insurance industry, which refused to cover such risks. French and German studies put the economic cost of a worst-case release at about 6000 billion euros – some 300% of the GDP of France, Germany or the UK.

Without asking their citizens, some governments exempted the nuclear operators from full insurance cover, both nationally and internationally, amounting to an unlimited implicit subsidy. They also allowed nuclear power plants to be sited only tens of kilometres from towns and cities. Yet most governments worldwide recognised that this was wholly unethical, as there were ample safe and sustainable alternatives. After Fukushima, Japan, Germany, and Switzerland announced nuclear phase-outs, and Italy decided against nuclear power. So any government proposing continued or new nuclear power must now explain siting distances less than hundreds of kilometres and why they are still 'licensing random premeditated murder'.

Since none of these fatal flaws - the real lessons of Fukushima - have been brought to the attention of the UK Parliament, I carried out two extensive studies, drawing on the ample evidence available on the Internet. The first is generic, with 15 pages and 89 references, and the second specific to Fukushima, with 73 pages and 231 references - both with all the Internet links. These include evidence for all the statements in this document and may be downloaded from: http://www.energypolicy.co.uk/nuclear.htm

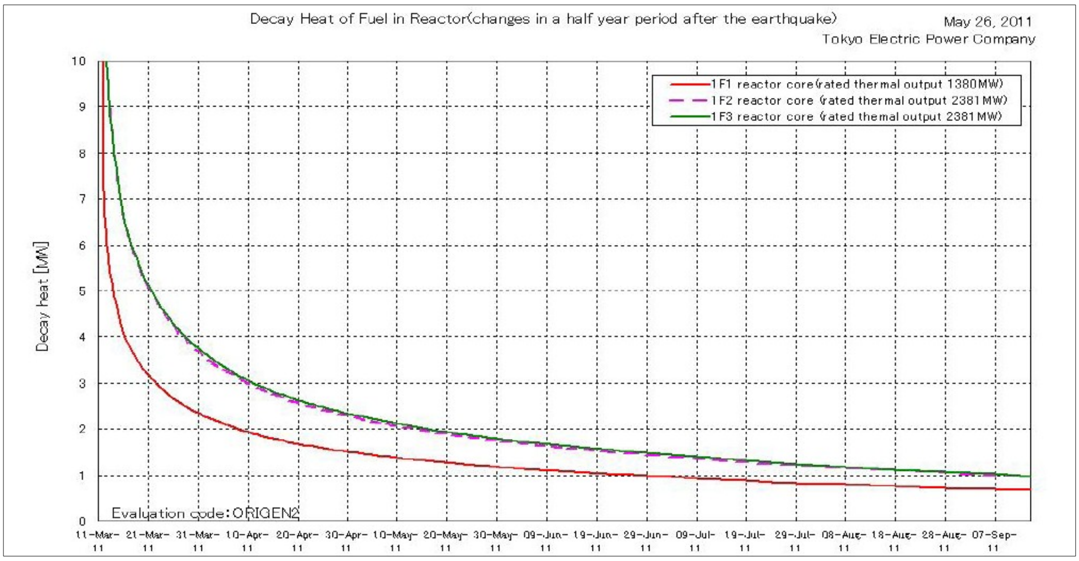
1 - Decay Heat and Nuclear Releases

Almost all existing and proposed nuclear power plants have reactor cores cooled with ordinary, 'light', water. These have several hundred fuel rods containing uranium enriched to about 3 to 4% U235. In normal operation, one or more loops, carrying water at high temperature, pressure and flowrates, transfer heat from the reactor core to the steam turbines.



For the Fukushima Daiichi reactors 1 to 3, the heat releases at full power were 1380, 2381 and 2381 MegaWatts thermal (MWth). However, unlike fossil-fired power plants, nuclear decay heat must be removed from the reactor core after shutdown, whether normal or emergency. While this heat declines with time, the reactor releases around 10 MWth for the first day and around 1 MWth after six months.

Decay Heat Curves – Fukushima



Loss of Cooling

When nuclear power plants lose both the grid connection and the standby generators is known as 'Station Blackout' (SBO). The cooling water valves and often the cooling pumps then depend upon batteries, which last only around 4 or 8 hours. With the reactor core still releasing some tens of MWth, unless grid or standby power is restored, the reactors and spent fuel pools will overheat, resulting in a Loss of Cooling Accident (LOCA). Reactor fuel can reach 'melt-down' in a few hours, releasing highly radioactive fission products. At Fukushima, this occurred after 4h (R1), 25h (R3) and 77h (R2). Moreover when overheated, the 'Zircalloy' fuel cladding reacts with water to produce hydrogen. Mixed with air, this has a very wide flammability range, so will almost certainly explode. The explosions will breach the final containment so releasing fission products to the environment. These are carried by the winds until they fall out over land or sea. They are also carried by any water pumped in for cooling. Since the quantities of such water are huge, it will enter the groundwater and rivers and, on coastal sites, the sea. Loss of cooling and resulting radioactive releases have so far occurred at Windscale (UK) 1957, Three Mile Island (USA) 1979, Chernobyl (Ukraine) 1986, and Fukushima (Japan) 2011.

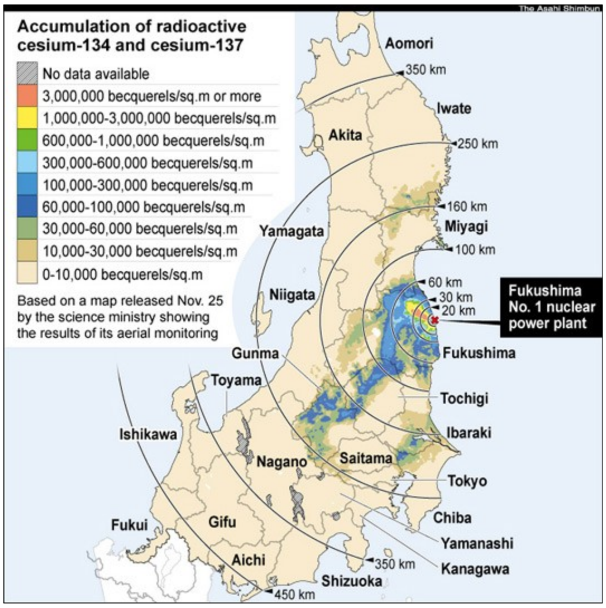
After the design 'burn-up', which takes about 18 months, the nuclear fuel rods are transferred to a spent fuel pool, to be water cooled for at least five years. Rather than transferring them to 'dry cask storage' at around a million dollars a cask, many pools have been 're-racked' to hold over five hundred fuel rods. As well as increasing the weight of spent fuel, this increases the total heat release and so shortens the time for the fuel to overheat in 'Station Blackout' conditions. Yet this practice is widespread in the USA, and was also the case at Fukushima. So far, no major radioactive releases have occurred from spent fuel pools. However, this was assumed for the 'worst cases' in both the Kondo and NII reports (see below).

Fission Products (examples)

Isotope	Boiling Point - C	Half Life	Radiological Equiv. I131
I131	184	8 days	1
Cs134	678	2.1 y	3
Cs137	678	30.2 y	40
Sr90	1384	28.82 y	20
(U235)	3818	704 million y	500 - 1000
Pu239	3232	24,360 y	10,000

Nuclear fission produces around 100 fission products. Since fuel mass has been traded for energy, most are lighter than the principal active element, U235. Many are volatile and have high radioactivity with relatively short half lives – the time to fall to one half. However, some plutonium isotopes are also produced, and more may have been included in the original fuel, which is then known as 'MOX' – short for 'Mixed Oxides'. Fukushima Reactor 3 had 6% MOX fuel. Plutonium is extremely dangerous, with even tiny amounts being lethal if inhaled.

Fukushima Daiichi - Fallout



This map shows that the radioactive fallout from Fukushima reached about 250 km. The land area contaminated with radioactive cesium to more than 10,000 Bequerels/m2 (Bq/m2) is about 30,000 km2, some 8% of Japan. Part of this will be uninhabitable for 10 to 20 years or more. According to the decontamination plan, the land area for which the radioactive dose to humans would be over 1 milliSievert/year (mSv/y) – the IAEA limit - is about 13,000 km2, some 3.5% of Japan.

2 - Health Effects of Nuclear Releases

When considering the health effects of nuclear releases, correct choice and interpretation of the evidence is vital, since the human consequences are potentially huge in space and time. The first issue is who can be relied on for the necessary data and the expertise to interpret it. The nuclear industry invariably cites the International Atomic Energy Authority (IAEA), but its declared purpose is the promotion of nuclear power. One might look to the World Health Organization (WHO), but this has been gagged since 1959, when it agreed to defer to the IAEA. After World War II, the US National Council on Radiation Protection (NCRP) considered mainly the evidence from the 'A-bomb' survivors, which ignored internal radioactivity. In 1952, the NCRP evolved into the International Commission on Radiation Protection (ICRP), who published their dose-effect model, relating the radioactive dose received by a human to the health effect.

The best evidence available on the health effects of nuclear releases is that from Chernobyl, now 25 years ago, most of which was originally published in Russian. The best summary available in English is that of Yablokov et al, 2009, based on about 1000 of over 30,000 original reports. As well as prompt injuries and deaths, the latent incidences, only manifest after decades, are far more numerous. Also radiation – especially internal - damages DNA, leading to still-births and genetic deformities, including in all future generations.

So when assessing the evidence, it is vital to follow the Precautionary Principle, as endorsed by the European Union. This means that all the evidence should be considered. Rather than depending on that from the 'A-Bomb' survivors, full use should be made of that from Chernobyl. Only the European Committee on Radiation Risk (ECRR), which is independent of nuclear interests, has done this. Also the dose-effect model should use not the low end of the evidence, as the ICRP, but the high end, as the ECRR. As it is, the interpretation of the evidence on health effects of ionizing (nuclear) radiation after Chernobyl, 1986, differs markedly – notably between the ICRP and the ECRR dose-effect models. At national level, the US Nuclear Regulatory Commission (NRC) and the UK Office for Nuclear Regulation (ONR) both cite the IAEA and the ICRP. Clearly they are too close to the nuclear industry for independence, having suffered 'regulatory capture'.

Fukushima Latent Health Effect Estimates

Author	Dose-Effect Model	Period - y	Excess Deaths
Cochran et al.	BEIR VII		350
Von Hippel, F.	ICRP	life	1000
Turkenburg, W.			~ 2000
Busby, C.	ICRP	50	3079
Busby, C.	Tondel	10	112,111
Busby, C.	ECRR	50	210,000
Vitazkova & Cazzoli	1 death/person-Sv	80	10,000 – 300,000+

At Fukushima, nearly 15,000 workers have received doses of radioactivity of up to 250 mSv. Excess cancers and resulting deaths may take up to 50 years or more to appear. Applying the ICRP dose-effect model gives estimated excess deaths over 50 years or more as 1000 to 3000, whereas applying others including the ECRR dose-effect model gives 10,000 to 200,000. About 80,000 persons were forced to evacuate parts of Fukushima prefecture.

Food and drink can carry fission products into the body, where they can accumulate and cause cancers. Also such internal exposure to radiation adds to any external exposure. So all suspect food must be tested and – if above limits – be discarded. Yet at the time of Fukushima, after more than 40 years of nuclear power, no such limits had been defined for Japan. Even in Europe, none had existed before Chernobyl. After some weeks, the Japanese government adopted the European limits, that were then found to be exceeded by many local foods. This has destroyed the businesses of farmers and fisherfolk over wide areas. The cost of compensation for persons and businesses has been estimated at 3.6 trillion yen ($ 47 billion).

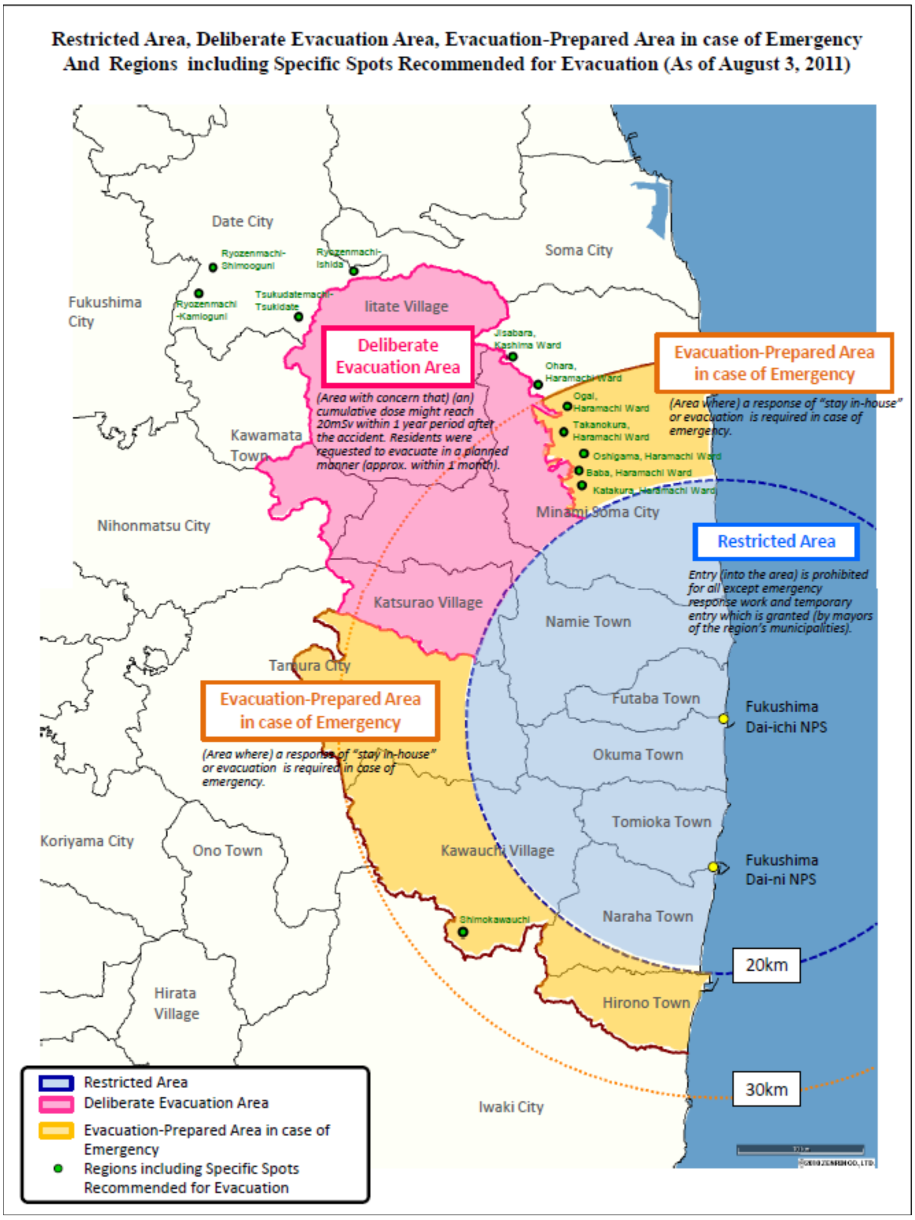
3 – Readiness for Nuclear Disasters

After a nuclear disaster, the power plant should be monitored and controlled from an Off-Site Center. Clearly this should be some distance away, with filtration of the ventilation air. Yet at Fukushima, the Off-Site Center was only 5 km from the power plant, and the ventilation system inadequate, so it had to be abandoned.

The first hours after nuclear disasters are critical, and plant operating data may be lacking, so a computer thermal model, representing the thermal behaviour of a reactor core and/or spent fuel pool with reduced or no cooling, must be used to predict the progression – e.g. to meltdown. Once a radioactive release occurs, a computer plume model, representing the flow of fission products in the atmosphere or ocean, is essential to predict the contents and path of the radioactive release cloud and to inform evacuations. This requires monitoring of radioactivity on and near the site, as well as real-time weather data on wind speed, direction and rainfall. The Japanese had such a plume model, known as SPEEDI, but the monitoring networks were disrupted by the earthquake and tsunami, so it was ignored. Also they had no instrument for making radioactivity measurements from the air and had to rely initially on aerial surveys carried out by the US military. They were thus unable to guide evacuations. This lead to an old persons hospital only 4km from the site being evacuated so fast that some 68 old people died immediately or soon afterwards. Also, one local authority sent people into, rather than away from, the fallout. It was two months before the final evacuation areas were decided by the central government, using data from the Chernobyl disaster and judgements on what was feasible, rather than data from around Fukushima.

Yet all these deficiencies were omitted or downplayed in the reports of the IAEA Fact Finding Mission of June 2011.

Fukushima Daiichi - Evacuation Areas



4 - Worst Cases and Probabilities

With Chernobyl and Fukushima, the nuclear releases to date are far short of the worst case. Where Chernobyl involved only one reactor, Fukushima involved three. Also, in both cases the release fractions - of the nuclear inventory of fuel and fission products - were small at around 1 or 2%. Of the radioactive fallout from Fukushima, only 19% fell on Japan, 2% on other land, and 79% on the sea. So the fallout over land could have been up to 5 times higher. The radioactive plume passed over Tokyo, but it was not raining. If it had been, the human health and other consequences would have been hugely higher.

The Kondo Report

Following the hydrogen explosions and radioactive releases at Fukushima on and after 2011-03-12, the then Prime Minister of Japan, Naoto Kan, required Shunsuke Kondo, Chairman of the Japan Atomic Energy Commission, to report on the 'worst case' scenario. This was delivered in late March 2011. It was not made public, but was reported in the Asahi Shimbun on 2012-01-07. The whole text was included in the 2012-02-28 report of the private panel on the Fukushima disaster chaired by Koichi Kitazawa. The 'worst case' was assumed to involve 1535 fuel rods - equivalent to two full reactor charges - in a spent fuel pool, with the radioactive plume assumed to fall out over major cities.

The Kondo Report concluded that the 'worst case' scenario would require mandatory evacuation of all within 170 km and 'voluntary' evacuation of all within 250 km. These include Fukushima City, with 290,000, Sendai, with 1 million and Tokyo, with 35 million.

The UK Nuclear Installations Inspectorate Report

Following Fukushima, the UK Nuclear Installations Inspectorate (NII) – the forerunner of the ONR - estimated that a 'reasonable worst case scenario' would release 10% of the radioactive caesium-137 and iodine-131 in the cores and one third of the caesium-137 in the spent fuel ponds. This would have released the equivalent of 9.92 million teraBecquerels (TBq) of radioactivity from iodine-131 into the open air. It was published by the Guardian on 2011-06-20.

Nuclear Releases – Actual and Worst Cases

INES	I131 equivalent - TBq	Event
(9)	5,000,000 – 50,000,000	Kondo 2011, Nuclear Installations Inspectorate 2011
(8)	500,000 – 5,000,000	
7	50,000 – 500,000	Chernobyl 1986, Fukushima 2011
6	5000 – 50,000	
5	500 - 5000	Windscale 1957, Three Mile Island 1979

Although well aware of the size of potential nuclear releases, the IAEA did not publish the International Nuclear Event Scale (INES) until after Chernobyl, 1986, with a maximum of 7. Yet the Kondo and the UK NII reports show that the real maximum is INES 9 – 100 times larger. (The INES is a logarithmic scale).

Probabilities

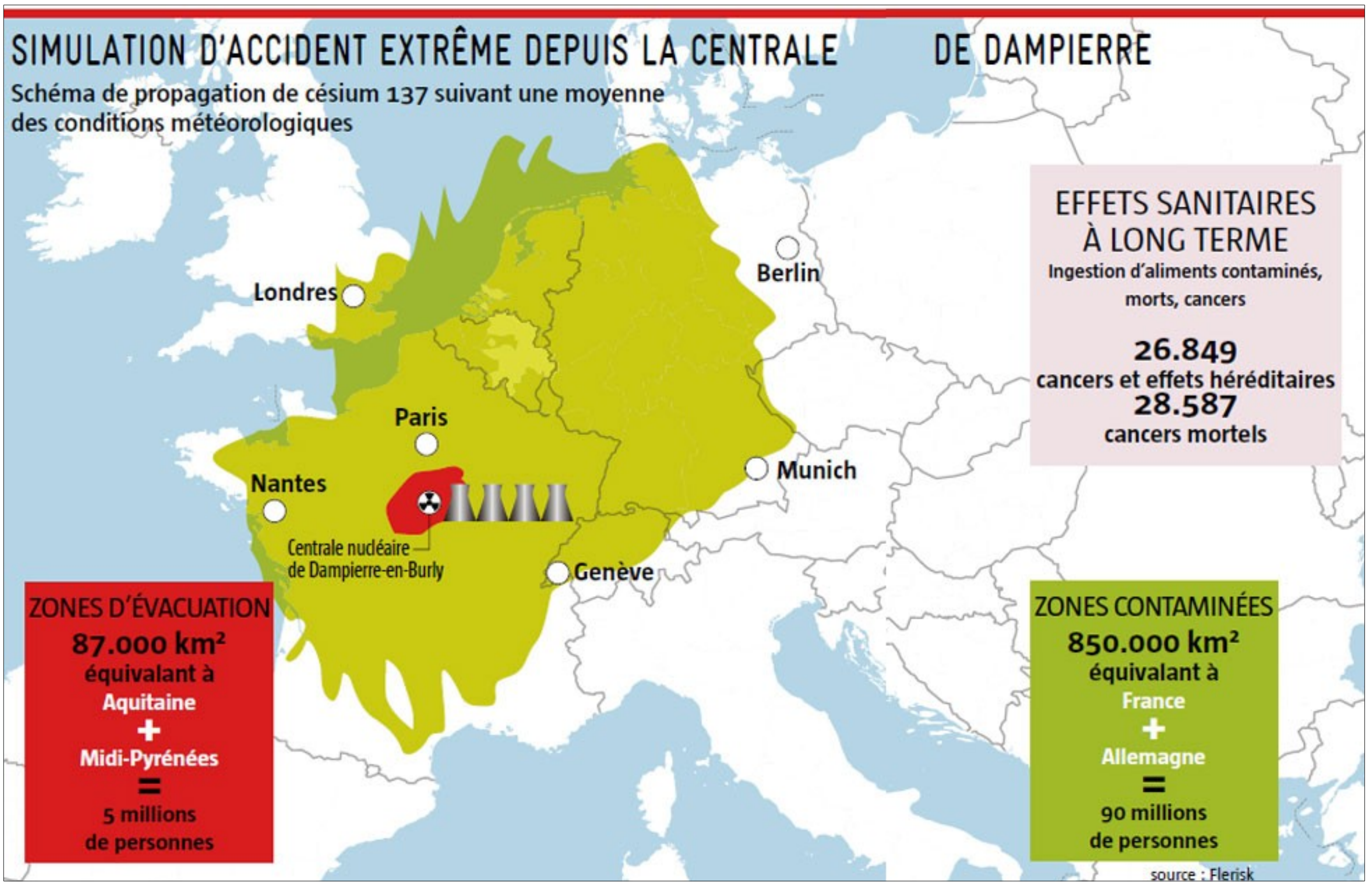
For early US Reactor Safety Studies, known as WASH-740 and WASH-1250, Risk was taken as Consequence. From WASH-1400 onwards, Risk was taken as Consequence x Probability. But this is invalid. Probabilistic Safety Analysis (PSA) requires identification of accident sequences (billions) and the Probabilities for each unit in the sequence (most unknown). In practice, far fewer sequences are considered, so all others are deemed unknowable. PSAs were only intended to help to achieve 'balanced' designs, and not to determine the overall probability. So the probability that they give must be an under-estimate and is not just unknown, but unknowable. Hence Probability must be taken as 1 – i.e. inevitable - and Risk must be taken as Consequence.

5 - Insurance and Ethics

From the beginning of civil nuclear power in 1954, the worldwide insurance industry refused to provide complete cover. The operators' interests were secured by limiting their liability with the Paris Convention of 1960 and the Vienna Convention of 1963. These were prompted by US Price-Anderson Act of 1957 and followed by the UK Nuclear Installations Act of 1965 whereby, apart from a nominal amount, the risk is carried by the State. Such 'Statutory Indemnities' are 'unquantifiable' – i.e. potentially unlimited. While full insurance is not available, the Versicherungsforen Leipzig found in 2011 that the mean sum payable for a nuclear disaster could be 6090 billion euros. The Ethics Commission appointed by the German Government after Fukushima found that withdrawal from nuclear energy is necessary, recommended and possible because there are less risky alternatives.

Patrick Momal, an economist at the French Institute for Radiological Protection and Nuclear Safety (IRSN), carried out in 2007 a study of disaster scenarios for the Dampierre nuclear power plant. The findings remained secret until 10 March 2013 (the second anniversary of Fukushima) when they were published in 'Le JDD' – a French newspaper also available online. The worst case would require the evacuation of five million from an area of 87,000 km2, and cesium 137 contamination would affect 90 million over an area of 850,000 km2, the equivalent of France and Germany combined. As shown by the map, the contamination would reach London. The total economic cost was put at 5800 billion euros.

Both these sums amount to some 300% of the GDP of Germany, France or the UK. But the human injuries and deaths, including in future generations, and land too contaminated for habitation, are irreplaceable.



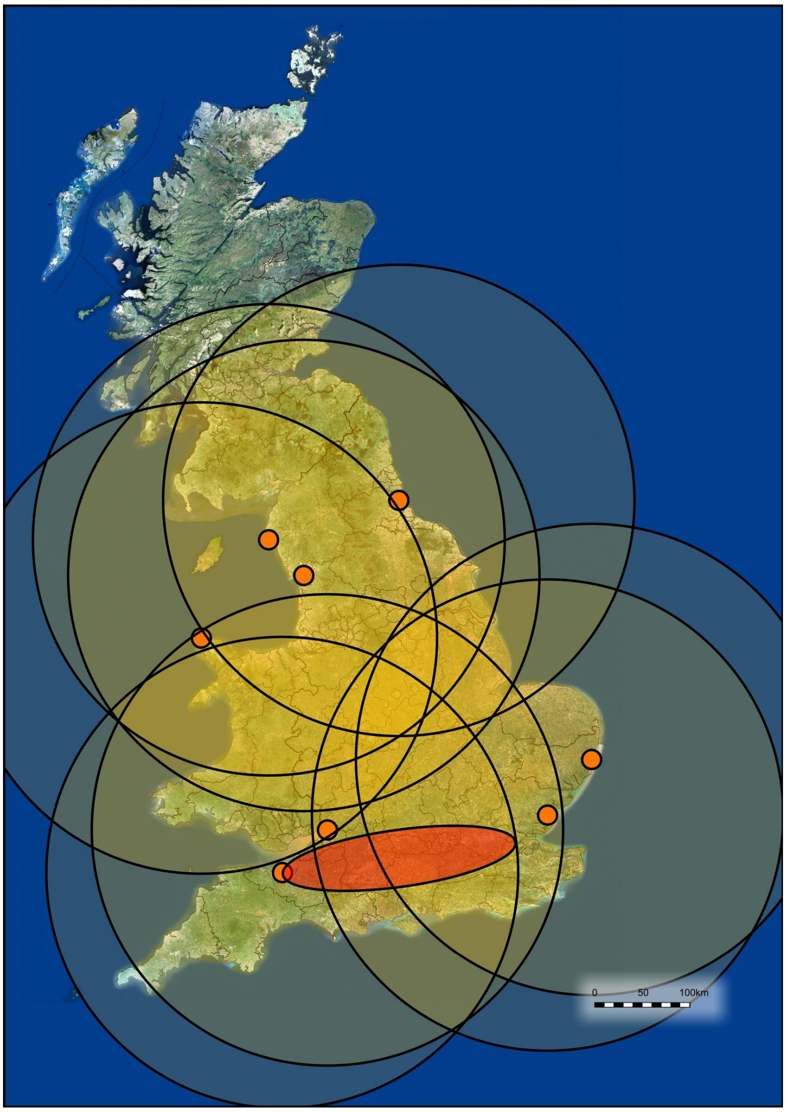
Even for the Fukushima radioactive release, the cost of the decontamination measures has been estimated at from 1.2 to more than 10 trillion yen ($130 billion). Hence the personal and business compensation and the decontamination cost may be up to 14 trillion yen ($ 180 billion). Yet the insurance fund available is only about 120 billion yen ($ 1.6 billion) per nuclear plant. Since TEPCO is virtually bankrupt, almost all the cost must be met by the taxpayers.

As it requires such colossal implicit subsidies from host nation-states, nuclear power can never be competitive.

6 - Siting Criteria

The UK criteria for siting nuclear power plants consider only a small radioactive release and fallout reaching 30 km. Yet the Fukushima release was about 4000 times as much and the Kondo Report 'worst case' release and the Nuclear Installations Inspectorate Fukushima 'reasonable worst-case scenario' release are each about 270,000 times as much. Like the IRSN report above, the Kondo and NII reports originate from within nuclear establishments, and should all be known by governments.

According to the Kondo Report, the worst case release – about 100 times that at Fukushima - would require evacuation for up to 250 km. This confirms what Dr Clifford Beck of the US Atomic Energy Commission (AEC) said in 1959: 'If worst case accidents are considered no site except one removed from populated areas by hundreds of miles would offer sufficient protection'.



This map of Great Britain shows that almost the entire population is within range of fallout extending 250 km from the eight sites. Moreover, fallout from Hinkley Point – carried on the prevailing westerlies – could reach London. So almost all the citizens of Britain and their descendants are threatened with death or injury by the existing and proposed nuclear power plants. In the words of Dr John Gofman, this is 'licensing random premeditated murder'.

7 - Rational Energy Policy

As the consequences of radioactive releases are completely unacceptable, all nuclear power plants should be phased out. In any case, after the next major nuclear release from any of the over 400 aging nuclear plants worldwide, the citizens will insist that all nuclear plants be shut down, as happened in Japan. As well as power shortages, this would result in huge stranded liabilities, with losses of lives, livelihoods and land. Yet under the existing laws and treaties, almost no recompense would be payable.

As well as Japan, Germany, Switzerland and Italy have now joined most other countries by phasing out and rejecting nuclear power and moving to supplying all energy services with increased energy efficiency and renewable energy sources. Unlike nuclear power, these are free from disastrous events with huge human and economic consequences and are low-carbon and sustainable. Moreover, as Denmark, Germany and others are showing, they offer major opportunities for consulting, design, manufacturing and service business both at home and abroad, so increasing energy security and employment.

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