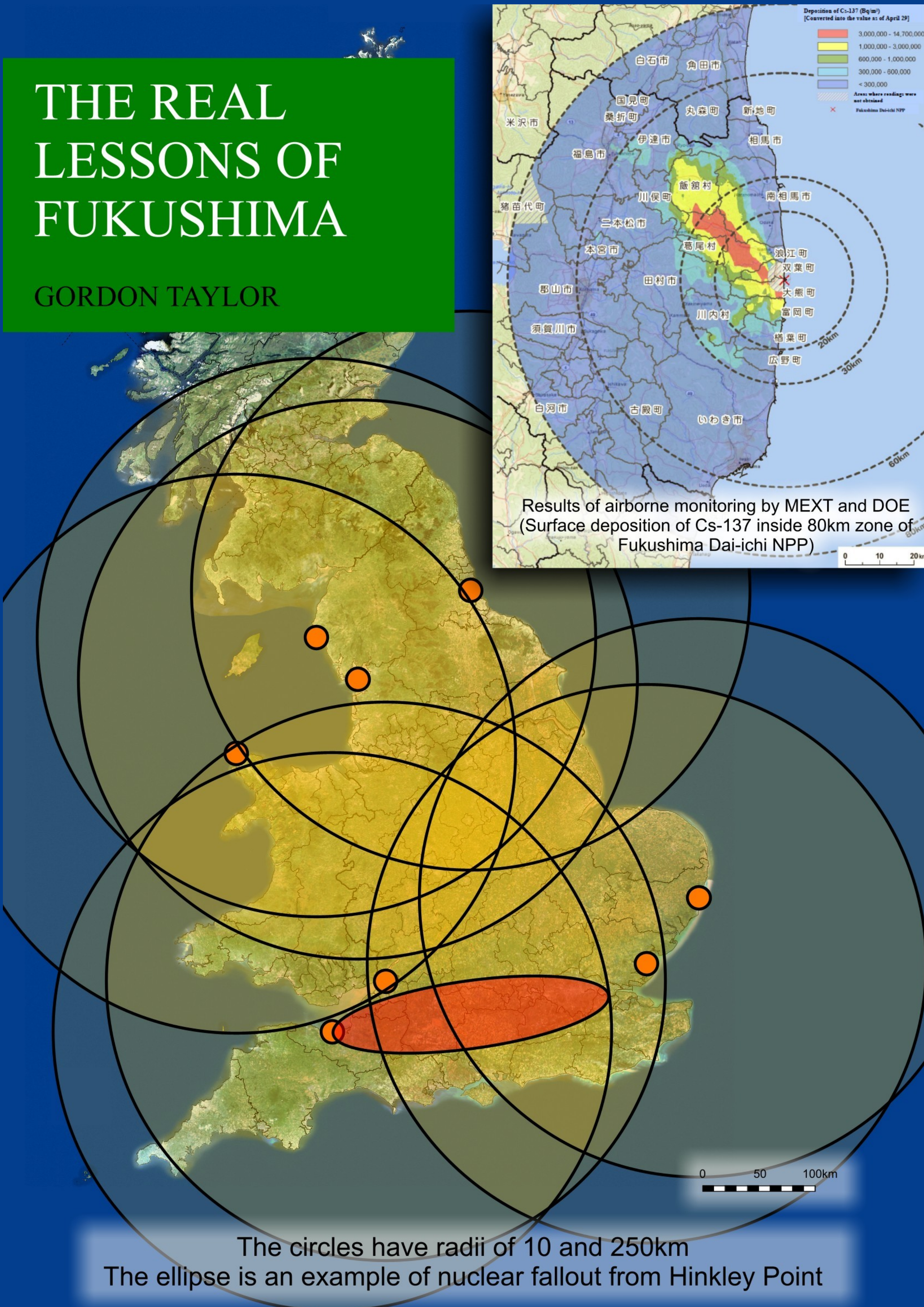
THE REAL LESSONS OF FUKUSHIMA

GORDON TAYLOR



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

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2012-04-11

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THE REAL LESSONS OF FUKUSHIMA SUMMARY

This study is based on evidence on the Fukushima disaster and it's consequences, almost all from the internet. Many quantitative studies have been found, but no proper studies from the IAEA or the UK ONR. The fast-moving and highly dangerous events of such a disaster require decision support. Thermal models of the reactors and spent fuel pools are essential to predict their behaviour under Station Blackout and to evaluate possible counter-measures. Also plume (dispersion) models of possible radioactive releases are essential to inform decisions on the magnitude and direction of evacuations. The Japanese have such a plume model, but it was ignored until later. Also they had no instrument for airborne radioactivity measurements at hand and had to rely initially on aerial surveys carried out by the Japan-based US Emergency Response Centers. These deficiencies were omitted or downplayed in the reports of the IAEA Fact Finding Mission, but most were included in the report of the Hatamura Panel.

Following the disaster, nearly 15,000 workers have received radiation doses of up to 250 mSv. Including the general public and using widely accepted dose-effect models, the estimated excess cancer deaths are 350 to 3000, while with other dose-effect models they are 100,000 to 200,000, though all these should be reduced by evacuation. About 80,000 persons have been forced to evacuate parts of Fukushima prefecture and live elsewhere. For the public, the dose criterion for evacuation was set at 20 mSv/y. However, for the decontamination plan the target dose limit was set equal to the ICRP dose limit of 1 mSv/y. This also requires more evacuation.

The area of land contaminated with radioactive cesium to more than 10,000 Bq/m2 is about 30,000 km2, some 8% of Japan. Even with considerable decontamination, a significant area of Japan will remain uninhabitable for 10 to 20 years or more. Moreover, land is required for storing the huge volumes of radioactive waste.

The household and business compensation cost may be Y 3.6 trillion and the decontamination cost up to Y 10 trillion or more, for a total of Y 14 trillion ($ 180 billion) or more. With insurance cover of only $ 1.6 billion, the shortfall may be up to $ 178 billion or more, which will have to be met by the taxpayers. This and other subsidies means that nuclear power can never be competitive. In any case, such consequences make it an ethical issue.

The Fukushima release source term is far less than the maximum possible and if it had fallen on a major city such as Tokyo, the consequences would have been even more horrific. The record shows that in severe accidents of INES 5 to 7, the contribution of human errors is 100%. Hence the worst case, with core meltdowns and the maximum physically possible release of radioactivity, must be considered. Germany, Switzerland and Italy have decided to join most other countries and phase out nuclear power. All the nuclear power plants in Japan will be shut down by the spring and the citizens may not allow any to be re-started. Economy minister Yukio Edano said he does not expect any nuclear power plant to be operating this summer, but thermal power and conservation efforts should be enough for the nation to get by.

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 NII Fukushima 'reasonable worst-case scenario' release about 270,000 times as much. According to the Kondo Report worst case, the fallout would require evacuation to 170 or 250 km or more, e.g. from Hinkley Point to Birmingham or London. Also the compensation for the land and property losses and the decontamination costs would be far larger than for Fukushima, at roughly £ 1 trillion. So the UK siting criteria are wholly inadequate and almost all the citizens of Britain are threatened by the existing and proposed nuclear power plants. In the words of Dr John Gofman, this is 'licensing random premeditated murder'. Thus the former must be phased out forthwith and the latter abandoned.

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This work was funded by the author.

The Full Study, with Tables, Figures and References, may be downloaded from:
http://www.energypolicy.co.uk/FukushimaRealLessons.pdf

THE REAL LESSONS OF FUKUSHIMA THE LESSONS

1. INTRODUCTION

An earlier paper 'The Case Against Nuclear Power' is based mainly on evidence prior to Fukushima. The sections are 'The Consequences of Radioactive Releases', 'The Probability of Radioactive Releases', 'Electricity and Greenhouse Gas Implications' and 'Electricity Costs'. The third section includes the demands for electricity, transport fuels and heat, all met by energy savings and wind energy.

The main reason for the present work is that the 'official' reports on Fukushima are complacent and inadequate, with the notable exception of that of the Hatamura Panel. This is due to the fundamental conflict of interests within the International Atomic Energy Agency (IAEA), which sees it's primary purpose as the promotion of nuclear power. Moreover, all the national nuclear regulatory agencies and the World Health Organization (WHO) defer to the IAEA, and thus lack the independence essential to their proper function.

2. EVENT PROGRESSION, RESPONSES AND DECISION SUPPORT

2.1 NUCLEAR POWER AND DECAY HEAT

The event progression under Station Blackout (SBO) and a Loss Of Cooling Accident (LOCA) can be estimated with thermal models of the reactors and spent fuel pools. With the known parameters of the plants, and the characteristics and inventory of the nuclear fuel, thermal models can simulate the event progression, including fuel melting and the production of hydrogen. However, they cannot predict whether any hydrogen will explode or the magnitude of any radioactive releases to the environment, known as 'source terms'. Provided that the assets are available, they require only known parameters plus operating data for the plants, so can be real-time. This is crucial since, as Fukushima has shown, nuclear fuel meltdown, hydrogen explosions and radioactive releases to the environment can occur within hours to days.

2.2 RESPONSES AND DECISION SUPPORT

Both the Nuclear Industrial Safety Agency of Japan (NISA) and Tokyo Electric Power Company (TEPCO) failed to consider the possibility of a SBO and a LOCA. Also, the off-site centre, thermal model, plume model and measurement capabilities – fixed and aerial – needed for decision support, were all wanting. The off-site centre only 5 km from the site had to be abandoned and in the hasty and unplanned evacuation of a hospital only 4 km from the site, at least 68 patients died. Despite this gross negligence, the IAEA Final Mission Report of 2011-06-22 described the Japanese emergency preparedness and response system as 'well organized'. However, the government Hatamura Panel Report of 2011-12-26 set out these failings in detail. Moreover, the private Kitazawa Panel report of 2012-02-28 quotes a U.S. official as saying that Japan's NISA declined to take measures, recommended by the U.S. Nuclear Regulatory Commission, to ensure the ability to cool down reactors in the case of terrorist attacks and other situations. (This means in the event of a SBO and a LOCA). That constituted a grave "failure to act," the report says. It seems unlikely that the UK response would be any better.

2.3 SEVERE ACCIDENT PROBABILITIES AND RISKS

In the US reports WASH-740 of 1957 and CRAC-2 of 1982, nuclear risk was expressed as the consequences of a 'maximum credible accident'. However in 1967, Farmer suggested that, for a given level of Risk in a 'balanced' design, the logarithm of the Consequence should be inversely related to the logarithm of the Probability. This became known as the 'Farmer curve' and interpreted as 'Risk = Consequence x Probability'. Yet regardless of the level of Risk, the Probability can never be zero, and while the Consequence can never be infinite, it can still be unacceptable. Even so, the Farmer curve has been used for risk assessment in all Reactor Safety Studies from WASH-1400 of 1975. This has had the effect – whether intended or not – of giving a false sense of security against unacceptable consequences.

The record shows that if an event reaches International Nuclear Event Scale INES 5, then it will almost certainly progress quickly to INES 7. Moreover, in severe accidents of INES 5 to 7, the contribution of human error is 100%. Above about INES 3.5, the actual probability of core melt increasingly exceeds that predicted by the safety analyses.

With three at Fukushima, the core melt frequency is now 1 in 8 years. Thus several would occur in the design life of a nuclear power plant, any one of which could be much worse than any so far. (See Section 11 below). Moreover, the danger depends very little on the safety of any new nuclear power plants, but very largely on that of the worldwide fleet of about 440 plants. As in the case of the Fukushima Daiichi Reactors 1 to 4, their ages are up to 40 years and more.

The case against nuclear power depends ultimately on logic. As all engineers know, whatever can happen will happen - and invariably at the worst possible time. The probability of earthquakes or tsunamis is irrelevant. Even the anticipated accident sequences can number billions, so with the unanticipated, the probability of any radioactive release up to the maximum physically possible is unknowable. Hence this must be taken as 1 – i.e. inevitable. So Probabilistic Safety Analyses are misleading and inadequate due to human errors, deterioration and logic. Thus the worst case - involving core meltdown(s) and the maximum physically possible release of radioactivity - and its consequences must be considered. (See Section 11 below). By suggesting otherwise, the governments, national nuclear agencies, IAEA, and the nuclear power plant suppliers and operators are all guilty of deliberate deception.

Masashi Goto and Hiromitsu Ino, advisers to Japan’s nuclear safety agency, say that the stress tests on the idle nuclear reactors do not guarantee their safety and call into question the impartiality of the IAEA, which approved Japan’s handling of the tests on 2012-01-31, Haruki Madarame, chairman of the Nuclear Safety Commission of Japan, established under the Cabinet Office, agrees and says that the results of the much-stricter second-stage tests - designed to ensure that Japan’s nuclear facilities will be safe even in an accident that far exceeds expectations - should also be considered.

Ino also noted: “It is highly unlikely that the IAEA can undertake a fair assessment. The agency promotes the nuclear industry and it is only investigating the stress tests for a short time,” he said. “The last IAEA report was very flimsy, and I fear it’ll be the same this time."

Economy minister Yukio Edano said he does not expect any nuclear power plant to be operating this summer, but thermal power and conservation efforts should be enough for the nation to get by. Such a phase-out would eliminate all the dangers of continued generation with nuclear power, including those from routine discharges.

3. RADIOACTIVE RELEASES

3.3 BIOLOGICAL EFFECTS OF RADIOACTIVITY

Freeman quoted Gofman: ‘Licensing a nuclear power plant is in my view, licensing random premeditated murder'. 'And I realized that the entire nuclear power program was based on a fraud--namely, that there was a *safe* amount of radiation, a permissible dose that wouldn't hurt anybody'. 'The new NRC was only supposed to involve itself in safety--no promotion. Which turned out to be one of the greatest lies in history. . . .’.

The energies of biologically significant levels of radiation are typically one million times those of chemical changes. These highly energetic emissions carry enough energy to tear electrons from neutral atoms and molecules. This can cause cancers and, by damaging DNA (deoxyribonucleic acid), also affect subsequent generations.

Strontium and actinides such as U-238 contribute to internal exposures, very strongly with the European Committee on Radiation Risk (ECRR) dose-effect model. So while the nuclides I-131, Cs-134, and Cs-137 are of great concern, others such as Sr-89 and Sr-90 and actinides, such as Pu-238, Pu-239, Pu-240 and Pu-241 and Np-239, are highly dangerous, especially if ingested or inhaled. Strontium can substitute for calcium and be retained in the bones and some actinides emit alpha particles. Both can cause cancer.

4. MEASUREMENTS OF RADIOACTIVITY FROM FUKUSHIMA

Of the radioactive attributes - alpha, beta, gamma, X-rays and neutrons - most simple instruments can measure only gamma radiation. By assuming the Quality Factor as 1, they measure the absorbed dose rate – in Greys/time – but display it as the (human) dose equivalent rate – in Sieverts/time. However, this is true only for gamma radiation. Therefore most reports give only dose values for the gamma emitters Iodine (131) and Cesium (134 and 137) and fail to mention that these are only indicative of the complete release. Moreover, the accuracy may be only +/- 50%. To identify and quantify all the nuclides that may be present requires further measurement and analysis. Measurements of radioactivity inside the human body require more elaborate equipment, such as whole body counters.

4.2 AERIAL SURVEYS

Although Japan has installed and operated nuclear power plants capable of major radioactive releases for over 40 years, the Japanese authorities had no instrument at hand for airborne radioactivity measurements. This was gross negligence. Instead they had to rely initially on aerial surveys carried out by the Japan-based US Emergency Response Centers.

4.3 SOIL SAMPLING FOR IODINE AND CESIUM

Kinoshita et al reported: 'Radioactive iodine, strontium, and cesium, which have large fission yields and low boiling points, present a large risk for internal radiation exposure via ingestion of contaminated agricultural crops'.

5. ESTIMATING SOURCE TERMS OF THE RELEASES FROM FUKUSHIMA

5.1 AIR-BORNE SOURCE TERMS FOR GASES AND VOLATILES

It is noteworthy that Wotawa was the first to publish an estimate of the source terms. He leads a group of full-time professionals who are conversant with plume modelling and have access to data from the Comprehensive Test Ban Treaty Organization (CTBTO) worldwide network. This is what it takes to get rapid results, which are vital when so many lives and livelihoods are at stake.

The source term values obtained by reverse estimation are notably consistent, with Chino et al's values for I-131 of 1.5E17 Bq and Cs-137 of 1.3E16 Bq, and the others within factors of about 3.

Michel estimated the total radioactive inventory for units 1 to 4, of which the IRSN values of the releases were - I-131: 1.8%, Cs-134: 0.5% and Cs-137: 0.5%. This shows that they could be very much higher. (See Section 11 below).

5.2 AIR-BORNE SOURCE TERMS FOR STRONTIUM AND ACTINIDES

According to the MEXT report, the accumulated effective dose for 50 years at points where the largest deposition amounts of strontium 90 was detected would be only about 0.12 mSv. (See Section 4.4). The Dose Conversion Factor for internal exposure of Sr-90 according to the ECRR model is about 60 times that according to the ICRP model. However, this would still be only about 7 mSv, compared with the largest amounts detected of Cs-134 at 71 mSv and Cs-137 at 2000 mSv. Also almost all the Np-239 and Pu-239 have been carried over the ocean.

5.3 SOURCE TERMS FOR THE SEA

TEPCO reported that the radioactive I-131, Cs-134 and Cs-137 source terms released to the sea via water discharges, deliberate and not, was 6.7E15 Bq. Other studies found that the Cs-137 released via airborne fallout was 2.8E16 Bq and the total, via both waterborne and airborne pathways, was 2.7E16 Bq, about 4 times as much.

6. CONSEQUENCES OF THE RADIOACTIVE RELEASES FROM FUKUSHIMA

6.2 LAND AREA AND PEOPLE AFFECTED

In the various studies, both the land areas and the people affected vary widely, depending on the values of the criteria. The land areas vary inversely with the deposition criteria in Bq/m2. In most cases, the number of people affected vary inversely with the dose criterion in mSv/y, but some estimates are based on simple deposition models, or on other studies. Also those favouring low dose-effect models may choose high dose criteria values and vice-versa. In these studies of Fukushima, the highest estimates of the land area – at 30,000 km2 (8% of Japan) – and of the people affected – at about 1 million – are both very large.

6.3 PEOPLE EVACUATED

Although there was some voluntary evacuation, the number of people to be evacuated depends mainly on the value of the exposure criterion applied. The dose limit was a political judgement, set initially at 20 mSv/y. So the number of people evacuated – at about 80,000 – was far smaller than the largest estimate of those affected – at about 1 million. However, the dose limit for the decontamination plan was later set equal to the ICRP recommendation for the general public, at 1 mSv/y. So to reduce the health effects, the evacuation zones should be far larger and more people should evacuate.

6.4 ANIMALS LEFT BEHIND

'Naoto Matsumura, Tomioka City, Fukushima Prefecture, Japan–the last man standing in Fukushima's Forbidden Zone. He will not leave; he risks an early death because his defiance of Tokyo Electric Power Company (TEPCO) and the government is his life now. He is not crazy and he is not going. He remains there to remind people of the human costs of nuclear accidents. He is the King of The Forbidden Zone; its protector. He is the caretaker or empty houses, a point of contact for those citizen who can't return. He takes care of the animals, "the sentient beings", that remain behind because no one else will'.

'Matsumura notes that "TEPCO and the Japanese government have never stopped lying, out of their good will, in order to avoid panic among the population. Such good intentions, of course.".'

6.5 DURATION OF LAND LOST AND PEOPLE EXCLUDED

The nuclear fallout from Fukushima includes Cs-137, which has a half-life of about 30 years. So unless the contamination and dose to humans can be reduced by removal, it will take many decades to die away. Therefore, even with decontamination, a significant area of Japan will remain uninhabitable for 10 to 20 years or more.

7. HUMAN HEALTH EFFECTS FROM FUKUSHIMA

7.1 PROMPT HEALTH EFFECTS

Following nuclear disasters, the people most exposed – both in dose and time - are the workers at the plant. Many are temporary and are 'burned out' by working in radioactive areas until they have received a certain dose and then replaced. Hence they are most likely to suffer prompt health effects – cancers and deaths.

Officials claimed that no workers showed health problems as a result of their exposure. However latent cancers can take 10 or even 50 years to appear, and about half would be lethal. (See Section 7.2 below). So TEPCO, the nuclear agencies and the government were all misleading the workers and the general public.

The authorities took advantage of the loyalty of firemen and sent them into high-risk areas with inadequate protection. Since many such rescuers have been involved, this death is likely to be followed by others.

Even though they are hired to be exposed to higher radiation, the temporary workers are treated far worse than TEPCO employees. Yet TEPCO should be fully aware of human rights and the capabilities of robots, so this is inexcusable.

7.2 LATENT HEALTH EFFECTS

Many nuclear reports and news items imply that the only health consequences are the 'prompt deaths and injuries' and fail to mention the (latent) excess cancers and resulting deaths that may appear only after 10, 50 or even 70 years. Even if workers escape prompt health effects, they are still liable to suffer latent health effects. Many studies estimate depositions and doses but stop short of estimating health effects. (See Section 6.2 above). Only the study by Vitazkova and Cazzoli used a plume model to estimate the deposition and dose, together with the population distribution before evacuation, a criterion to determine the number of people affected and evacuation assumptions, to estimate the human health effects. The other studies estimated the health effects with simple models or by comparison with other data, such as that from Chernobyl.

The human health effects vary widely, depending on the dose-effect model used. Thus the BEIR (Biological Effects of Ionizing Radiation) VII model implies 100s, the ICRP model implies 1000s, while the Tondel, ECRR and '1 death/person-Sv' models imply 100,000s of excess cancers and deaths. The BEIR and ICRP have adopted the lowest dose-effects in the literature, and ignored much low-dose data. Moreover, release source terms can include up to 100 different nuclides, but only a few are normally considered, so any estimates of the human health effects must be low. In this case, the source terms of Sr and Pu seem to be very small. (See Section 5.2 above). Even so, these human health effects omit those of ingesting contaminated food and water. (See Section 8 below). Furthermore, radioactivity – especially inhaled alpha-particles – causes genetic damage, which will be manifest as still-births, deformities, cancers and premature deaths in future generations. This contravenes the 'precautionary principle', which would be met by using the ECRR model.

The evacuations should reduce these latent health effects, but if the Fukushima evacuees were to return before decontamination and/or decay of the radioactivity over decades, they would increase again. So the evacuees must be informed accordingly before any return is permitted, much less encouraged. (See Section 4.5 below).

Many quantitative studies of the Fukushima disaster and consequences – such as release source terms, ground deposition, human dose, land area, people affected and health effects - have been published (mostly in English) by individuals and organizations in many different countries. These include Austria, France, Germany, Japan, Netherlands, Switzerland and the USA. However, no proper studies have been found from the IAEA or the UK Office of Nuclear Regulation (ONR), which casts doubt on their readiness and ability to carry out such studies.

7.3 HEALTH CHECKS

The Fukushima prefectural government plans to test some 360,000 people who were under 18 on March 11 throughout their lives and all of the approximately 2 million residents for at least 30 years.

8. FOOD AND WATER CONTAMINATION FROM FUKUSHIMA

The health effects are increased if radioactivity is ingested with food and drink - and especially if inhaled – causing additional, internal exposure. (See Section 3.1 above). Japan has had nuclear power plants for more than 40 years, yet had no guidance levels or restrictions for nuclear substances on food at the time of the Fukushima nuclear disaster. The reason for this is unknown, but is at least incompetence. That said, Europe did not develop such standards until the fallout from Chernobyl arrived in 1986. In both cases, the nuclear interests knew of the dangers, but failed to alert the politicians to the need for such standards, even though the criteria values would be political judgements. To comply with the current German radioactivity limits for food, the EU limits should be reduced by around 40-fold. However the World Health Organization (WHO) has relinquished jurisdiction to the IAEA, which like the ICRP and European Atomic Energy Community (EURATOM), is dominated by the nuclear industry and their commercial interests.

8.1 LAND FOOD CONTAMINATION

The requirements for testing land foods for radioactivity are very considerable. They include staff, instruments and compensation for any that is rejected as over the limit. Moreover, this must continue for 10 to 20 years or more.

8.2 SEA FOOD CONTAMINATION

Since the radioactive half-life of Cs-137 is 30 years, and the radioactivity in sea foods is very hard to estimate, it is necessary to have comprehensive testing. The activity values of radioactive cesium (Cs-134 + Cs-137) in sea foods from the coastal areas now only rarely exceeds the limit of 500 Bq/kg while that in other species from fishing grounds some 100 km away measures less than 10 Bq/kg. Even so, the coastal fishing industry has been greatly damaged.

9. DECONTAMINATION AND RADIOACTIVE WASTE STORAGE AFTER FUKUSHIMA

9.1 DECONTAMINATION OF WATER AND LIQUID RADIOACTIVE WASTE STORAGE

Radioactive waste water will continue to accumulate until the reactor and fuel pool decay heat falls, reducing the cooling load, and the radioactive water cleanup plant throughput catches up with the water demand for cooling. Until then, fresh water must be supplied for 'once-through' cooling, and the resulting radioactive waste water would require ever more 'temporary' storage tanks and/or discharges to the sea.

9.2 DECONTAMINATION OF LAND AND SOLID RADIOACTIVE WASTE STORAGE

Minimising the loss of developed land will require vast efforts at decontamination, but this will be impractical for undeveloped land and forests. Also some land will be required for storing the huge volumes of radioactive waste.

10. COSTS OF HUMAN, LAND AND WATER CONSEQUENCES AND DECONTAMINATION AFTER FUKUSHIMA

For Fukushima, the household and business compensation may be Y 3.6 trillion and the decontamination cost up to Y 10 trillion or more for a total of up to Y 14 trillion ($ 180 billion) or more.

These costs may or may not include the equipment for and testing of human health and any treatment required for this and future generations, the necessary research on soil-to-food transfer factors and of testing foods for radioactivity for 10 to 20 years and more and the food discarded. However, all these should be paid by TEPCO. Yet no recompense is possible for the human misery, injury and loss of life-span, including of future generations, or likely for the loss of homes and communities and the economic outputs of farming, fishing, and industry in the contaminated areas.

10.1 INSURANCE, SUBSIDIES AND ETHICS

With insurance cover of only $ 1.6 billion the shortfall may be up to $ 178 billion or more, which will have to be met by the taxpayers. In the UK, the nuclear accident risk is carried by the State, under the Nuclear Installations Act of 1965. Such 'Statutory Indemnities' are described as 'unquantifiable', which means 'unlimited' or 'infinite'.

The Versicherungsforen Leipzig found that the hypothetical mean insured sum payable for a nuclear disaster in Germany could be 6090 billion (6 trillion) euros. (See Section 12 below). At 1 euro = £ 0.88, if shared by the 54 nuclear power plants in Japan and spread over 50 or 10 years, the value would be about 14 or 110 p/kWh. Then at £ 1 = 130 yen, it would be 18 or 143 yen/kWh. This and other subsidies means that nuclear power can never be competitive.

The German Government set up an Ethics Commission for a Safe Energy Supply. This found that: 'The withdrawal from nuclear energy is necessary and recommended to rule out future risks from nuclear in Germany. It is possible because there are less risky alternatives'. 'The Ethics Commission has come to the conclusion that a safe energy supply can be achieved which provides more jobs in business and manual trade without compromising environmental protection, whilst also avoiding a power shortage and having to import nuclear energy'.

11. FUKUSHIMA COULD HAVE BEEN FAR WORSE

11.1 LARGER INVENTORY AND RELEASE FRACTION

The Fukushima release source term is far less than the maximum possible from Reactors 1 to 4. Compared with the Chino et al Fukushima I-131 release estimate of 1.5E17 Bq, the I-131 source term for the NII 'reasonable worst case scenario' is about 1E19 Bq, which is about 66 times higher. This is consistent with the estimates of the radioactive inventories of I-131. It is roughly 100 times higher than INES 7 – the highest value defined by the IAEA – but it would be INES 9. The total for all nuclides would be larger. (See Sections 5.1 and 5.2 above). Therefore the total release source terms could be far larger than anything that has occurred to date. Also, multiple reactors and spent fuel pools per site and nearby sites would further increase the potential total release.

11.2 MORE OF THE RELEASE FALLING ON LAND AND MAJOR CITIES

If the release had fallen on land and especially a major city such as Tokyo (population about 35 million), complete evacuation would be impossible and the health and economic consequences would have been much worse.

11.3 COMBINATION OF FAR LARGER RELEASE AND FALLING ON MAJOR CITIES

If a worst case release fell on a major city, complete evacuation would be impossible and the health effects would affect millions. The compensation and decontamination cost for a worst case release could be between $ 936 billion and $ 4.8 trillion – i.e. roughly £ 1 trillion. This is of the same order as the hypothetical mean insured sum payable for a German nuclear disaster of 6 trillion euros estimated by the Versicherungsforen Leipzig. So the consequences of a major radioactive release are comparable to those of nuclear weapons, but are self-inflicted. Moreover, the NII estimate of the 'reasonable worst case scenario' and the Kondo report on the worst case consequences are from within the UK and Japanese nuclear communities. So such horrific consequences are undeniable.

When the next major release occurs, the citizens will demand immediate shut-down of all nuclear power, as has happened in Japan. Yet they would still suffer huge health effects, a damaged country and vast amounts of radioactive waste. Germany, Switzerland and Italy have already decided to join many other countries and phase out nuclear power. Meanwhile Japan has shut down most of the nuclear power plants, and will shut down the rest this spring. Whether the citizens will allow any to be re-started remains to be seen.

In the light of the Kondo report on Fukushima, studies of the consequences for a worst case release must be carried out for each country where nuclear power plants are installed or proposed. Since fallout crosses national boundaries, the consequences should include those for neighbouring countries. Plume models can be used to estimate the ground and marine depositions for various combinations of wind and rain. Following the 'precautionary principle', the ECRR model must be used to estimate the human health effects. Moreover, these studies must be carried out independently of all nuclear power interests, including the IAEA and the national nuclear regulatory agencies.

12. CONSEQUENCES OF A MAJOR RADIOACTIVE RELEASE IN THE UK

Dr Clifford Beck of the US Atomic Energy Commission (AEC) said in 1959: 'If worst conceivable accidents are considered no site except one removed from populated areas by hundreds of miles would offer sufficient protection'.

Following the nuclear accident at Three Mile Island in 1979, Sandia produced the 'CRAC-2' study on the siting criteria for nuclear power plants in 1982. Most were located near to major cities and for a major release, the 'Peak Early Fatalities' were estimated at up to 100,000.

The UK Government has proposed ten sites for new nuclear power plants, of which three are very close together. Also, it is proposed to install more than one unit per site, each far larger than Fukushima in output and hence nuclear fuel inventory. Just who and how many would suffer death, injury, exclusion and economic loss would depend on which site produced the release, its magnitude, the direction of the wind, and whether it was raining or snowing as the plume passed. The ground level concentration pattern of radioactive fallout - for a constant wind over a level surface - is approximately elliptical. For the Kondo Report worst case release, with evacuation compulsory to 170 km and voluntary to 250 km or more, this could be from Hinkley Point to Birmingham or London. By extrapolation, at the ICRP dose criterion of 1 mSv/y, the radius would be about 800 km. (See Section 11.3). Moreover, fallout could fall on other nuclear power plants - particularly for the Sellafield cluster - and compound the consequences. Also the land and property losses and decontamination costs would be far larger than for Fukushima, at roughly £ 1 trillion. (See Section 11.3). This is of the same order as the hypothetical mean insured sum payable for a German nuclear disaster of 6 trillion euros estimated by the Versicherungsforen Leipzig.

Fig. 4 is a map of Great Britain, showing the areas threatened by the ten proposed nuclear power plants and an example of fallout from Hinkley Point extending 250km to London. After Fukushima, such consequences would be inexcusable, especially as the UK suffered from Windscale and Chernobyl. So the UK siting criteria are wholly inadequate and almost all the citizens of Britain are threatened by the existing and proposed nuclear power plants. In the words of Dr John Gofman, this is 'licensing random premeditated murder'. Thus the existing nuclear power plants must be phased out forthwith and the proposed ones abandoned.

13. CONCLUSIONS

This study is based on evidence on the Fukushima disaster and it's consequences, almost all from the internet. Many quantitative studies have been found, but no proper studies from the IAEA or the UK ONR. The fast-moving and highly dangerous events of such a disaster require decision support. Thermal models of the reactors and spent fuel pools are essential to predict their behaviour under Station Blackout and evaluate possible counter-measures. Also plume (dispersion) models of possible radioactive releases are essential to inform decisions on the magnitude and direction of evacuations. The Japanese have such a plume model, but it was ignored until later. Also they had no instrument for airborne radioactivity measurements at hand and had to rely initially on aerial surveys carried out by the Japan-based US Emergency Response Centers. These deficiencies were omitted or downplayed in the reports of the IAEA Fact Finding Mission, but most were included in the report of the Hatamura Panel.

Following the disaster, nearly 15,000 workers have received doses of up to 250 mSv. Several have received more and at least one has died due to internal radiation. Excess cancers and resulting deaths may take up to 50 years to appear. Using widely accepted dose-effect models, the excess cancer deaths are estimated as 350 to 3000, while with other dose-effect models they may be 100,000 to 200,000, though all these should be reduced by evacuation.

About 80,000 persons have been forced to evacuate parts of Fukushima prefecture and live elsewhere. Radioactivity above Japanese government limits has been found in many foods, including rice, beef and fish. This would cause internal exposure if eaten, and has destroyed the businesses of farmers and fisherfolk over wide areas. The compensation for persons and businesses has been estimated at 3.6 trillion yen ($ 47 billion).

The area of land contaminated with radioactive cesium to more than 10,000 Bq/m2 is about 30,000 km2, some 8% of the land area 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 dose to humans would be over 1 mSv/y is about 13,000 km2. It would require removing about 29 million cubic meters of topsoil and fallen leaves, and such radioactive waste needs land for storage. The cost of the decontamination measures have 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. In principle, the electric power companies should pay the rest, but TEPCO is virtually bankrupt. So almost all the cost must be met by the taxpayers. This and other subsidies means that nuclear power can never be competitive.

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 higher by up to 5 times. The radioactive plume passed over Tokyo, but by chance it was not raining. If it had been, the human health and other consequences would have been hugely higher. Scenarios with larger releases, all over land and over crowded cities, have consequences that are even more horrific.

Germany, Switzerland and Italy have decided to join many other countries and phase out nuclear power. Also Japan has shut down almost all the nuclear power plants, and will shut down the rest this spring. Whether the citizens will allow any to be re-started remains to be seen. Economy minister Yukio Edano said he does not expect any nuclear power plant to be operating this summer, but thermal power and conservation efforts should be enough for the nation to get by.

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 NII Fukushima 'reasonable worst-case scenario' release is about 270,000 times as much. According to the Kondo Report, the worst case release would require evacuation for 170 or 250 km or more, e.g. from Hinkley Point to Birmingham or London. Also the compensation for the land and property losses and the decontamination costs would be far larger than for Fukushima, at roughly £ 1 trillion. So the UK siting criteria are wholly inadequate and almost all the citizens of Britain are threatened by the existing and proposed nuclear power plants. In the words of Dr John Gofman, this is 'licensing random premeditated murder'. Thus the former must be phased out forthwith and the latter abandoned.

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This work was funded by the author.

The Full Study, with Tables, Figures and References, may be downloaded from:
http://www.energypolicy.co.uk/FukushimaRealLessons.pdf

THE REAL LESSONS OF FUKUSHIMA THE FULL STUDY

1 INTRODUCTION

An earlier paper 'The Case Against Nuclear Power' is based mainly on evidence prior to Fukushima. The sections are The Consequences of Radioactive Releases, The Probability of Radioactive Releases, Electricity and Greenhouse Gas Implications and Electricity Costs. The third section includes the demands for electricity, transport fuels and heat, all met by energy savings and wind energy. [1]

Fukushima may apply to the prefecture, it's major city and the nuclear power plant, but here usually means the disaster. This study is based on evidence on the Fukushima disaster and it's consequences. Where possible, published papers with quantitative data are used. However for many topics, no published papers have been found, or the primary sources were in Japanese, so secondary sources and articles in English from the media – newspapers, broadcasters, and internet – are used. Within each section, the quoted sources are usually in chronological order. Dates are shown as yyyy-mm-dd to avoid ambiguity, but nuclides are shown with the mass numbers before – as 137Cs – or after – as Cs-137. The units of measurement used are those of the Systeme International. Thus radioactivity is in Bequerels – Bq, absorbed dose is in Grays – Gy, and dose equivalent is in Sieverts – Sv. The values of radioactive parameters such as reactor core and spent fuel pool inventories, source term releases, ground depositions and human doses can range from very large to very small, so are usually expressed in exponential notation, such as 1.5E17. With measurements of radioactivity, there are inherent variations (uncertainties) due to instrument limitations and the effects of wind, rain and terrain. Hence agreement between estimates and measurements within factor 10 is good and within less, such as factor 3, is excellent. However such values are essential to inform decisions on counter-measures, evacuations and exclusion zones.

1.1 DESCRIPTIONS AND REPORTS

Descriptions and reports of the Fukushima disaster are given in many documents, of which these are very useful.

Date	Author	Organization	Number of Slides	Reference
2011-03-24	Mohrbach, L.	VGB PowerTech	60	2
2011-04-01	Braun, M.	Areva	33	3
2011-05-16	Michel, R.	University of Hannover	78	4
2011-06-16	Turkenburg, W.	University of Utrecht	138	5
2011-06-27	Omoto, A.	University of Tokyo	55	6
2011-09-30	Shepherd, J.E.	California Institute of Technology	239	7
2011-11-08	Uspuras, E. et al	(various)	21, 22	8

Table 1: Descriptions of the Fukushima Disaster.

These descriptions are presentations, with photographs, diagrams and data. All have references, while Shepherd also includes hyperlinks. Several were independent of and/or published before any of the 'official' reports (below). The Uspuras et al paper and presentation have the most recent information on the progression and status of the reactors.

Date	Organization	Short Title	Number of Pages	Reference
2011-06-01	IAEA	Preliminary Mission Report	5	[9]
2011-06-08	NISA	Japan Government Report	387 + Attachments	[10]
2011-06-08	IAEA	Activities Report	22	[11]
2011-06-22	IAEA	Final Mission Report	162	[12]
2011-10-14	IAEA	Preliminary Remediation Report	20	[13]
2011-11-15	IAEA	Final Remediation Report	81	[14]
2011-12-26	Hatamura Panel	Executive Summary of Interim Report	22	[15]

Table 2: Reports on the Fukushima Disaster.

These reports are 'official' documents, largely textual, with some data. Most have references, some with hyperlinks.

> An earlier paper 'The Case Against Nuclear Power' is based mainly on evidence prior to Fukushima. The sections are 'The Consequences of Radioactive Releases', 'The Probability of Radioactive Releases', 'Electricity and Greenhouse Gas Implications' and 'Electricity Costs'. The third section includes the demands for electricity, transport fuels and heat, all met by energy savings and wind energy.
>
> The main reason for the present work is that the 'official' reports on Fukushima are complacent and inadequate, with the notable exception of that of the Hatamura Panel. This is due to the fundamental conflict of interests within the IAEA, which sees it's primary purpose as the promotion of nuclear power. Moreover, all the national nuclear regulatory agencies and the WHO defer to the IAEA, and thus lack the independence essential to their proper function.

2 EVENT PROGRESSION, RESPONSES AND DECISION SUPPORT

2.1 EVENT PROGRESSION - NUCLEAR POWER AND DECAY HEAT

A nuclear power plant uses a nuclear reactor to produce steam, which is converted by a turbine and generator to electricity. The overall efficiency is about one-third, so in normal operation the reactor heat is about three times the electrical output. For Fukushima Daiichi 1, the reactor heat is about 1380 MWth, and for 2 and 3, 2381 MWth.[16] However – unlike coal-, oil- and gas-fired power stations - even after an emergency shut-down, the reactor continues to produce significant amounts of nuclear decay heat. This declines quickly in the first 5 days, then much more slowly. For reactors like Fukushima Daiichi 1, the decay heat is roughly 8 MWth, and for 2 and 3, about 12 MWth. [17]

The main reactor cooling system has very powerful pumps. To remove decay heat after shut-down, all three reactors have a Residual Heat Removal System. In addition, Reactor 1 has an Isolation Condenser and Reactors 2 and 3 have Reactor Core Isolation Cooling. [18] However, all such systems have electrically-controlled valves and some have electric pumps. These are normally powered from the station output or if this fails, from the grid. If the grid connection is lost, they may be powered by standby diesel generators, or if these fail, from batteries. Some reactors – including Fukushima Daiichi 1, 2 and 3 - have batteries designed to last for 10 or 8 hours, but those in some similar reactors in the USA are for only 4 hours. A nuclear power plant that loses the grid connection and all standby generators is in Station Blackout. Unless one or other can be restored before the batteries are exhausted, it will experience a Loss of Cooling Accident. In this the decay heat will raise the temperatures in the reactor core enough to destroy the cladding (~ 1800 C) and melt the fuel (~ 2700 C) in a few hours. [19] This means that the operators have very little time to avert a disaster.

On 2011-03-11, the Fukushima Daiichi nuclear power plant was shaken by a massive earthquake, and inundated by a huge tsunami. This resulted in Station Blackout (SBO) and a Loss of Cooling Accident (LOCA), with the fuel cores of Reactors 1, 2 and 3 melting down and leaking from the reactor pressure vessel. The Zircaloy fuel cladding reacted with water (steam) at high temperatures and produced hydrogen. This reacted with oxygen from the air, causing explosions that breached the final containment, releasing radioactive materials, mainly gases and volatiles (airborne aerosols).

Tokyo Electric Power Company (TEPCO) data on the radiological dose equivalent versus time was plotted by the German Nuclear Safety Organization (GRS) on 2011-03-23. [20] This showed the meltdowns and hydrogen explosions of Reactors 1, 2 and 3 and Spent Fuel Pool 4, which lead to radioactive releases. However, the degree of meltdown could not be shown directly by instruments. Instead, the Areva presentations include the progression of the event, with the reactor temperatures derived from thermal models. [21] [22] NHK reported estimates of melt-downs for Reactors 1, 2 and 3 from the US NRC as 67%, 44%, 30% and TEPCO as 70%, 30% and 25%. [23] Later, NHK reported revised estimates from TEPCO as 55%, 35% and 30%. [24] On the second day of the International Atomic Energy Agency (IAEA) Mission, TEPCO published data showing that - timed from the earthquake - core damage (melting) began for Reactor 1 after 4 h, then Reactor 3 after 25 h and Reactor 2 after 77 h. [25] According to the National Industrial Safety Agency of Japan (NISA), TEPCO, in the Government report to the IAEA, reported that Reactors 1, 2 and 3, may have melted through. [26] TEPCO used the MAAP thermal model to estimate if and when reactor meltdown and melt-through would occur. [27]

Large and Associates reported that:

> 'The IAEA Mission Team fail to shed any further light whatsoever on the events and circumstances that culminated in the catastrophic failure and radiation release from three operational nuclear power plants, and for the explosion and radioactive release from the spent fuel pond of a fourth but defueled nuclear reactor. It provides no explanation or reason for the substantial and confusing delays that occurred in the aftermath management of the incident – for example, why the INES Level 7 declaration was delayed for one month when it was so obvious from the onset that this was a very serious radiological incident indeed; why TEPCO, with the knowledge of NISA, delayed the release of data showing a complete fuel melt and breach of the RPV (Reactor Pressure Vessel) containment for two months; why the SPEEDI monitoring results were not published in full from the onset; on the confusion and delays over the radiation dose limitation system applied in the off-site public domain; and so on and so forth. Holding back and/or the incomplete publication of this information and data could have particular relevance to the effectiveness of the countermeasures being applied over the off site areas involving tens if not hundreds of thousands of members of public.' [28]

A later report from Large and Associates found that the plant operator TEPCO covered up the multiple meltdowns for two months, and that the regulator NISA and the Government chose to believe them. Worse still, the IAEA Fact Finding Mission (2011-05-24 to 06-02), lead by the UK's Chief Nuclear Safety Inspector Mike Weightman, also turned a blind eye. The summary concludes that it is beyond our wit to foresee all possible circumstances and events, yet the radiological consequences are very severe. [29]

Turkenburg reported that meltdowns had already been detected on the second day:

> '• A reading on March 12th shows that radioactive tellurium was detected 7 kilometers away. Tellurium is produced during the melting of nuclear fuel.
>
> • Three hours before the data was collected, the government expanded the radius of the evacuation area around the plant from 3 kilometers to 10 kilometers. But NISA reported several hours later that the fuel was intact.' [30]

By denying the meltdowns, NISA caused the evacuations out to 20 km and beyond to be delayed and thus the dose to humans to be increased. [31]

> The event progression under Station Blackout (SBO) and a Loss Of Cooling Accident (LOCA) can be estimated with thermal models of the reactors and spent fuel pools. With the known parameters of the plants, and the characteristics and inventory of the nuclear fuel, thermal models can simulate the event progression, including fuel melting and the production of hydrogen. However, they cannot predict whether any hydrogen will explode or the magnitude of any radioactive releases to the environment, known as 'source terms'. Provided that the assets are available, they require only known parameters plus operating data for the plants, so can be real-time. This is crucial since, as Fukushima has shown, nuclear fuel meltdown, hydrogen explosions and radioactive releases to the environment can occur within hours to days.

2.2 RESPONSES AND DECISION SUPPORT

That the consequences of a Loss of Cooling Accident could be serious had been known at least since the US WASH-740 study of 1957. [32] This was long before the GE Boiling Water Reactors (BWRs), as installed at Fukushima, had been designed. So the Japanese nuclear agency NISA and the operator TEPCO should have known that in such an event, immediate responses are needed to manage events at the power plant, and if an off-site release is in prospect, to inform the public on the extent and direction of evacuation. To reduce the dangers to lives and property requires decision support assets – people, instruments and computer models - together with criteria on the ground deposition and dose to humans for evacuation and on radioactivity limits for food and water. Later, decisions are needed on the duration of exclusion zones, and on the extent of decontamination areas.

The path of the radioactive release source term, the ground deposition and the dose to humans can be estimated with plume (dispersion) models. These are needed to inform decisions on the extent and direction of evacuations. With the assets available, including real-time weather data, at least the direction can be given. However, estimating the ground deposition and the dose to humans, and thus the extent of evacuations, also requires radioactivity measurements. These can come from a network of fixed stations or from detailed aerial surveys. The former had recently been completed as part of the SPEEDI system and if all the assets are available, it should be almost real-time. However, even with all the assets available, the latter requires extensive flights in close pitch passes over the area, so can take weeks. The distribution of the ground deposition and dose to humans can also be determined by soil sampling. Even with the assets available, this requires many samples for reasonable precision, especially in hilly terrain, so can also take weeks.

The radioactive release could threaten the plant operators and so impair measurement and control. However, both thermal and plume models can be used remotely, together with measurements made off-site or even further away.

TEPCO and the Japanese Government were initially in disarray, but the need for decision support was immediately appreciated by the US authorities. [33] A plume model had been developed in Japan as part of the SPEEDI system. [34] Mochizuki reported that:

> 'Command center of US army in Japan asked for radiation information on 3/14/2011 (2011-03-14). Ministry of Foreign Affairs of Japan asked SPEEDI data from Nuclear Safety Technology Center through Ministry of Education, Culture, Sports, Science and Technology to forward it to US army every hour. US army was receiving the information at least until July'. [35]

Also, the German Federal Office for Radiation Protection (GRS) developed RODOS for this purpose. [36] Moreover, RODOS is also used by Finland, Spain, Portugal, Austria, the Netherlands, Poland, Hungary, Slovakia, Ukraine, Slovenia, and the Czech Republic. [37]

The IAEA Final Mission Report included:

> 'Conclusion 6: Japan has a well organized emergency preparedness and response system as demonstrated by the handling of the Fukushima accident'. [38]

However, the Hatamura 'Investigative Committee' (Panel) wrote:

‘P 4. ...once a nuclear accident occurs, a local nuclear emergency response headquarters (“ local NERHQ”) shall be established close to the accident site, as center of the emergency response coordination. A local NERHQ is to be located at a local standing facility for emergency responses and measures (“Off-site Center”).

The Off-site Center of the Fukushima Dai-ichi NPS was located about 5km from the Fukushima Dai-ichi site but it could not function as intended. The Off-site Center had to be evacuated because of the following reasons: difficulty in assembling its staff members due to damaged transportation and heavily congested traffic caused by the Earthquake; loss of telecommunication infrastructures, power cut, shortages of food, water and fuel; and elevated radiation levels in the building which was not equipped with air cleaning filters.

In other words, the Off-site Center lost its functions because:

i It was not assumed that nuclear disasters may strike simultaneously with outbreak of earthquake; and

ii Its building structure was not designed to withstand elevated radiation levels, although it was intended for use in nuclear emergencies.’

‘P 5. At the time of the Accidents, decisions on emergency responses were made primarily by the NERHQ (located on the 5th Floor of the Prime Minister’s Office). All relevant Ministers and the Chairman of the Nuclear Safety Commission (“NSC”) of Japan were convened there. Senior executives of TEPCO were also present.

The emergency gathering team members (on the underground floor) could hardly get hold of the discussions taking place on the Fifth floor. When the integrated responses by the entire Government set-up are of critical importance, there was insufficient communication between the Fifth floor (NERHQ) and the emergency gathering team.’

‘P 7. In the meantime, the NPS emergency response headquarters and the TEPCO head office in Tokyo had the opportunities from the reports from the shift operators on duty and other sources, which could have prompted them to notice the loss of functionality of the IC (isolation condenser). But they failed to notice and maintained their view that the IC was operating normally. These incidents in sequence indicate that not only the shift operators on duty but also the NPS emergency response headquarters as well as TEPCO head office in Tokyo did not fully understand the function of IC operation. Such situation is quite inappropriate for nuclear operators.

As soon as the IC lost its function, Unit 1 required alternative water injection for core cooling as quickly as possible, and it became necessary to depressurize the reactor vessel for allowing low-pressure water injection. In the view of the Investigation Committee, misjudgment of the operational situation of the IC caused delay in alternative water injection and PCV (primary containment vessel) venting. As a result, an earlier opportunity for core cooling was missed.’

‘P 8. Furthermore, due attention should have been paid to the depletion of battery that is essential for HPCI (high pressure coolant injection) operation under the station blackout (SBO) conditions. If it had been done, the NPS emergency response headquarters could have initiated much earlier alternative water injections by using fire engines. The NPS emergency headquarters was considering and preparing for mid or long-term measures of water injection by using the standby liquid control system as soon as power supplies resume. However, nothing was done to deploy fire engines for urgent alternative water injections, until the operators on duty reported to the NPS emergency response headquarters about the trouble after the HPCI operation had been manually stopped. The delay was caused solely due to the lack of recognition at the NPS emergency response headquarters of the necessity and urgency of alternative water injections into Unit 3.’

‘P 9. Monitoring data of radiation levels in the environment are indispensable for preventing radiation exposure and planning evacuation of people. However, as a result of many monitoring posts washed away by the Tsunami or became inoperative by power cut, monitoring system lost its sufficient capabilities, under the influence of preceding earthquakes and tsunami. Furthermore, in the initial stage of responses to the Accidents, there were confusions over utilization of monitoring data. In particular, the government lacked an attitude of making the monitoring data promptly available to the public. Even when some data were made public, they were only partial disclosure.’

‘P 10. The System for Prediction of Environmental Emergency Dose Information (SPEEDI) is also to play an important role in planning prevention of radiation exposure and evacuation of local population. However, the system was not utilized at the time of issuing instructions to evacuate. The communication links were disrupted and inoperative due to the earthquakes, and the SPEEDI could not receive the basic source term information of discharged radioactivity. It was therefore not possible for the SPEEDI to estimate atmospheric dispersion of radioactive materials on the basis of the basic source term information. However, it is possible for the SPEEDI to estimate the course of dispersion of radioactive materials, making assumption of the unit amount of discharge (1 Bq/h). And actually those estimates were then calculated by the system. Such calculation only predicts the direction of dispersion and relative distribution of radioactivity. But, if the information were provided timely, it could have helped local governments and population to choose more appropriate route and direction of evacuation.

Since the local NERHQ lost its functionality, the Government NERHQ or NISA should have taken the role of providing the SPEEDI results to the public. But none of them had the idea of making use of this information. MEXT, the competent ministry for SPEEDI, did not come to realize to providing the SPEEDI information to the public by themselves or through the Government NERHQ. Furthermore, since March 16, the clear division of responsibility was kept undefined between MEXT and NSC on the utilization of the SPEEDI. This was one of the reasons for the delay of making the SPEEDI results public.’

‘P 11. The government issued instructions for evacuation over several times. The decisions were made at the Government NERHQ only on the basis of the information and views of the senior members of relevant ministries and TEPCO at present. There is no evidence that any official representing MEXT as the competent ministry of SPEEDI was present at the Government NERHQ. No knowledge of SPEEDI was utilized in the decision-making process. Since the SPEEDI had not been functional in a full form, the conclusions of evacuation zoning might have been the same as the government decisions. But it should be pointed out as problematic that the point of view of utilizing the SPEEDI was totally missing in planning the evacuation strategy.

The government instructions for evacuation did not reach promptly all the relevant local governments subject to Evacuation Areas. Moreover, the instructions were not specific nor in detail. The local governments had to, with insufficient information, make decisions to evacuate, locate evacuation destination, and evacuation procedures. One major reason for such confusion is considered to be that the government and electric power companies had not tackled fully the issue of evacuation once a nuclear disaster occurs.’

‘P 12. The Investigation Committee notes the following points in order to prepare for possible recurrence of such an accident.

i. Public educational programs should be formulated and implemented for the general public to have basic knowledge in daily life on how radioactive materials be released, dispersed, and deposited on the ground once a nuclear accident occurs at a nuclear power station, and the possible health effects of radiation exposure.

ii. Local governments should prepare for the evacuation operation system, considering the unique characteristics of nuclear accident, and should implement regular training exercises in a realistic manner with earnest participation of the population.

iii. The evacuation may involve a large number of populations from the order of thousands to tens of thousands. With this in mind, the local governments should prepare in normal times for establishing concrete plans to ensure transportation, traffic control, evacuation location in remote place, food and drinking water at the destinations, etc. In particular, special measures are needed for the evacuation of the socially vulnerable people: those in medical facilities, nursing homes for senior citizens, and welfare institutions, and severely affected patients at home, severely disabled people and others.

iv. Nuclear disasters affect broad areas. Above-mentioned measures should not be left alone to local governments. The prefectural and national government should proactively involve themselves with the local governments (cities, towns, villages) in formulating above-mentioned measures for evacuation planning, disaster prevention planning and their operation.’

‘P 13. In the wake of the Accidents, quite a few cases were observed where the manner of providing information by the government gave rise questions and doubt on the part of the populations in the surrounding areas who were forced to evacuate and people in the whole nation that the government was not providing truth promptly and accurately. Such examples included, among others, the status of the reactor cores (core meltdowns, in particular), the critical conditions of Unit 3, and explanations on radiation effects on health such as “No immediate impacts on human health”, which was difficult to understand.

The following tendency was observed: transmission and public announcement of information on urgent matter was delayed, press releases were withheld, and explanations were kept ambiguous. Whatever the reasons behind, such tendency was hardly appropriate, in view of communication in an emergency.’

> 'P 19. It is not easy to admit an absolute safety never exists and to learn to live with risks. But it is necessary to make effort toward realizing a society where risk information is shared and people are allowed to make reasonable choices.' [39]

The Asahi Shimbun reported that:

> 'According to the interim report issued Dec. 26 by a government panel looking into the nuclear accident, such confusion in evacuating areas around the crippled plant could have been prevented if the central government used calculations made by the System for Prediction of Environmental Emergency Dose Information (SPEEDI). Instead of using SPEEDI, which forecasts the spread of radiation from a nuclear accident, the government in effect simply told residents to flee, according to the report. According to the report, Namie moved its local government functions to the Tsushima district in the northwestern part of the town following evacuation instructions from the central government early on March 12. Namie officials then instructed residents to evacuate to the Tsushima district or at least to a radius between 10 and 20 kilometers from the Fukushima No. 1 plant'. ''The central government widened the evacuation zone to a radius of 20 km, forcing Namie town officials to guide evacuees further away, according to the interim report'. 'But the SPEEDI calculations would have shown that the Tsushima district was susceptible to high levels of radiation from the plant'. 'On March 15, the Namie mayor decided to evacuate residents to Nihonmatsu, according to the interim report. But that northwesterly route also ended up putting residents in the direction where radioactive materials were spewing from the plant, the report said. Because the central government did not release the forecast data from SPEEDI, many residents fled without knowing that information.' [40]

The BBC TV Programme 'Inside the Meltdown' noted that firemen had to deal with three meltdowns and Prime Minister Naoto Kan had to gamble with lives to prevent a greater catastrophe. It emerged that TEPCO had no plan for Station Blackout yet Kan was advised that if the reactor pressure vessel was breached, parts of northern Japan would be uninhabitable for centuries. Kan authorised TEPCO to release radioactive steam and hydrogen, but TEPCO did not know how to do it without electricity, yet radioactivity levels were rising. It was a disaster. The engineers realised that nuclear meltdown had begun, a fact that the Government would not acknowledge for months. The Prime Minister thought that TEPCO was hiding something, so he went to Fukushima. He insisted that they vent the reactors. Members of the public were still near the plant, so were told to leave. The plant manager said that they were doing their best, but moving the valves was hard. The radioactivity near the vents was high, but Kan wanted it done regardless. Each worker was limited to 17 minutes. After 9 minutes they found the hand wheel. One worker received a dose equal to five years. The reactor containment was vented, and power restored, so those in the control room relaxed. But Reactor 1 exploded, 'then we all panicked'. The plant manager feared with worst, with massive radiation released, but after an hour, the level stabilized, and they realized that it had been a hydrogen explosion. The Government spokesman played down the situation, but it was sliding out of control.

Kan asked for a (model) simulation to be run and the worst case was evacuation to 200 to 300 km. On the afternoon of March 12, the Government widened the evacuation zone to 20 km and more than 100,000 people evacuated. However, some were fleeing into (the path of the fallout and thus) greater danger, which has angered the people concerned. SPEEDI predicted the path but officials at NISA were unwilling to give it to Kan. Soldiers were called in. They wore suits that protected against particles, but not against deadly gamma radiation. Also, radioactive particles were leaking past the masks. That night, Kan was woken to be told that TEPCO was considering withdrawing all (250) workers from the plant, with six reactors and seven fuel pools. Kan went to the TEPCO headquarters in Tokyo to forbid the withdrawal. 'The fate of Japan hangs in the balance. All those over 60 should be prepared to lead the way in a dangerous place. Otherwise we will be handing Japan over to an invisible enemy. This will affect not just Japan – but the whole world'. TEPCO executives still deny that they intended to withdraw all the workers. The 'Fukushima 50' were in the control room, but the reactors were unmanned.

U.S. specialists arrived and feared that the Japanese were out of their depth. They flew a surveillance drone over the plant. This showed that the third hydrogen explosion had exposed the spent fuel pool (of Reactor 4). Kan ordered dumping of water into this from the air. Although those who had done this at Chernobyl had died, the Japanese airmen did it – from a helicopter at a height of about 100 m. The first run hit but the second missed. The Americans measured radiation but it did not fall. So they told US citizens to evacuate to 50 miles (80 km) and made secret plans for their 90,000 citizens to leave Japan. All British citizens within 80 km were advised to evacuate.

Tokyo firemen were sent in. They chose from those over 40 and the captain made a reconnaissance. The plan was to take water from the sea and lay 800 m of hose to put it into the fuel pool. To limit the radiation dose, the work had to be completed within 60 minutes. This was done and the firemen returned to Tokyo. Then with radiation falling, TEPCO sent in more workers to install more pipes for cooling. Kan said 'Until then we had been pushed and pushed. Finally the system was in order. The turnround began'. TEPCO now believes that the molten fuel in Reactor 1 has come to rest on the concrete base below the reactor pressure vessel. Fukushima has contaminated 100s of square kilometers of north-eastern Japan. The coastline near the plant may be uninhabitable for 20 years. Kan asked 'When the world has 1000, 2000, 3000 nuclear plants - - - can we call that a safe world to live in ? That first week, we walked a razor thin line'. [41]

The Asahi Shimbun reported:

‘Private panel blames TEPCO's 'systematic negligence.

Systematic negligence by Tokyo Electric Power Co. contributed to the Fukushima nuclear disaster, according to a non-government panel. The Independent Investigation Commission on the Fukushima Daiichi Nuclear Accident drew on evidence from 300 or so individuals, including key figures such as former Prime Minister Naoto Kan, former industry minister Banri Kaieda and Haruki Madarame, chairman of the Nuclear Safety Commission of Japan (NSC). However, a request for interviews with TEPCO's top management was rejected by the company. Its report, compiled on Feb. 27, argues that the Fukushima nuclear crisis was essentially a man-made disaster, rather than being the inevitable result of the magnitude-9.0 Great East Japan Earthquake on March 11.

The panel, headed by Koichi Kitazawa, former chairman of the Japan Science and Technology Agency, blames systematic failures by TEPCO, the operator of the stricken plant, and weaknesses in the government’s regulatory regime for the disaster triggered by the earthquake and massive tsunami it spawned. The report says the accident worsened because TEPCO falsely believed on the night of March 11 that the isolation condensers at the No. 1 reactor were operational. A delayed injection of water into the reactors, late venting of gas to reduce internal pressure, and problems with decision-making because of the absence of TEPCO's president, Masataka Shimizu, and chairman, Tsunehisa Katsumata, before 10 a.m. on March 12, all contributed to the loss of control at the plant, its says. The panel describes TEPCO’s failings as amounting to “systematic negligence” and characterizes the culture of the company immediately before the disaster as irresponsible. "TEPCO used to make light of the culture of nuclear safety," according to the report.

The panel also argues that the government's safety regime contributed to the disaster. In 2007, the International Atomic Energy Agency called for a clearer distinction of roles between the Nuclear and Industrial Safety Agency and the Nuclear Safety Commission of Japan (NSC). However, the NSC did not comply with the recommendation, arguing that Japan's safety regulations were “very excellent in the light of international standards and have been highly evaluated.” Measures to deal with very severe accidents were not obligatory, and international cooperation to deal with possible terrorist threats to plants proceeded slowly. The report’s authors argue that Japan’s nuclear safety regulations were “Galapagosized”, a concept in Japan referring to a perceived tendency for some Japanese industries to isolate themselves from international standards like the isolated wildlife on the Galapagos Islands.

Simulation results on the diffusion of radioactive substances, forecast by the government's System for Prediction of Environmental Emergency Dose Information (SPEEDI), were not released to the public immediately following the disaster. Also, the “off-site center”, a facility located about 5 kilometers from the Fukushima No. 1 nuclear plant that was supposed to serve as a response base in case of emergencies, did not fulfill its functions during the crisis.

These “appeared to have been *make-believe* arrangements to reassure local residents”, the report says.

The panel calls for the creation of a body to deal with severe disasters and accidents and the fortification of functions to advise the prime minister on science and technology issues.

On the facts of the disaster, the panel largely backs the findings of the interim report of the government's Investigation Committee on the Accident at the Fukushima Nuclear Power Stations, although there are some points of divergence.

For example, while the government committee largely accepted TEPCO’s assertion that its president never asked for a total withdrawal of staff from the Fukushima No. 1 nuclear plant, the private panel is more skeptical.

Shimizu, the TEPCO president at the time, told the government on the night of March 14-15 that he wanted to evacuate workers from the Fukushima No. 1 nuclear plant. The prime minister's office took his words to mean that he was indicating a total withdrawal, but TEPCO has since argued that was a misunderstanding.

The government investigation committee's report said that Shimizu did not expressly say that reactor control personnel would remain at the plant, because he took it for a matter of course. The private panel's report distances itself from that interpretation of the March events, pointing out that TEPCO did not give any figure for the number of personnel that would be required to stay at the time. The private panel's report also quotes a U.S. official as saying that Japan's NISA declined to take measures, recommended by the U.S. Nuclear Regulatory Commission, to ensure the ability to cool down reactors in the case of terrorist attacks and other situations. That constituted a grave "failure to act", the report says. The report also includes the whole text of the "worst-case scenario" drawn up in late March by Shunsuke Kondo, chairman of the Japan Atomic Energy Commission, at Kan's request.' [42] (See Section 11 below.)

The NHK programme 'The Core of the Disaster' noted that the off-site centre was only 5 km from the Fukushima plant and the designated hospital only 4 km. Although intended for emergencies, both were within the emergency planning zone of 10 km, which implied 50,000 evacuees. The government had no accurate idea of what had exploded so – basing their decision on Chernobyl – they considered evacuation to 30 km, implying 210,000 evacuees. However, this was thought to be too many, so they settled on 20 km, and 78,000 evacuees. The order to the hospital came suddenly and at least 68 patients died during or shortly after the unplanned evacuation. [43]

Both NISA and TEPCO failed to consider the possibility of a Station Blackout (SBO) and a Loss Of Cooling Accident (LOCA). Also, the off-site centre, thermal model, plume model and measurement capabilities – fixed and aerial – needed for decision support, were all wanting. The off-site centre only 5 km from the site had to be abandoned and in the hasty and unplanned evacuation of a hospital only 4 km from the site, at least 68 patients died. Despite this gross negligence, the IAEA Final Mission Report of 2011-06-22 described the Japanese emergency preparedness and response system as 'well organized'. However, the government Hatamura Panel Report of 2011-12-26 set out these failings in detail. Moreover, the private Kitazawa Panel Report of 2012-02-28 quotes a U.S. official as saying that Japan's NISA declined to take measures, recommended by the U.S. Nuclear Regulatory Commission, to ensure the ability to cool down reactors in the case of terrorist attacks and other situations. (This means in the event of a SBO and a LOCA). That constituted a grave "failure to act," the report says. It seems unlikely that the UK response would be any better.

2.3 SEVERE ACCIDENT PROBABILITIES AND RISKS

In the US reports WASH-740 of 1957 and CRAC-2 of 1982, nuclear risk was expressed as the consequences of a 'maximum credible accident'. [44] [45] However in 1967, Farmer suggested that, for a given level of Risk in a 'balanced' design, the logarithm of the Consequence should be inversely related to the logarithm of the Probability. [46] This became known as the 'Farmer curve' and interpreted as 'Risk = Consequence x Probability'. Yet regardless of the level of Risk, the Probability can never be zero, and while the Consequence can never be infinite, it can still be unacceptable. Even so, the Farmer curve has been used for risk assessment in all Reactor Safety Studies from WASH-1400 of 1975. [47] This has had the effect – whether intended or not – of giving a false sense of security against unacceptable consequences.

Hirschberg et al reported that:

'The number of possible accident sequences can range into billions...'. '... up to 100 (different) source terms (nuclides) can result'. 'These are normally reduced for the Level 3 assessment, which deals with offsite consequences, into a manageable number of source terms. The reduction is performed on the basis of simple tools, which in [US NRC, 1989] consisted of a model, named PARTITION, that roughly estimates early and latent fatalities for each source term using the release of activity for Iodine and Cesium alone'. 'The overall uncertainty band for the consequences typically corresponds to a factor of ten.' [48]

Vitazkova & Cazzoli reported that:

> ‘The design of technical equipment in NPPs (nuclear power plants) is so complex and so many degrees of freedom can be identified for particular systems that it is impossible to reliably know or predict the response of the plant as a whole because of the multiple relationships among systems. Above this, human interactions are added influencing the already complex relationships of the systems. Unlike system response, human interactions even though led by procedures, have many more degrees of freedom as compared to technical systems. Therefore, errors in operator interventions (errors of omission or commission) can always occur however perfect the procedures.
>
> 1. In this respect, treatment of errors of omissions within the PSA (Probabilistic Safety Analysis) human reliability analyses (HRA) should be performed conservatively. The history of accidents bears evidence to the following fact [1, 2, 3, and 56]: Total contribution of human errors to all severe accidents is 50% and to accident of (International Nuclear Event Scale) INES5 and higher it is 100%.
>
> 2. Moreover, errors of commission are not part of the PSAs. The contribution of error commissions (when known) is about 30% to the total CDF (Core Damage Frequency) according to historical evidence. Of these, the large majority is given by errors of commission as initiators to the accident. The contribution to accidents of INES5 or higher is almost 35%. From this alone it can be concluded that one of the major contributors to the present historical evidence of accidents in nuclear power plants comes from conditions that cannot be assessed in PSA because they refer to operator interventions that could be totally random and irrational before and under severe accident conditions, and by themselves should be considered as separate possible initiators to accidents.
>
> These two facts based on historical evidence show that no matter how designs will be improved or which design is considered, from the point of view of root causes of accidents with core damage, the contribution of human interventions will be always the limiting factor to plant safety and risk because it is not possible to eliminate personnel from plant operation (management, maintenance, surveillance, tests, startup of the systems, emergency situation interventions)’’.
>
> ‘1. According to historical evidence of accidents in view of the INES scale (in terms of consequences) and their frequencies shown in Figure 1 it can be stated, that the target of balanced plant risk in all release modes is not met. Risk from accidents with higher rating increases and exceeds the risk given by IAEA safety criteria (see Section 4 and 5) which is in contradiction with results of ALL PSAs currently performed, all of them at or well below the red limit INES line both in frequencies and consequences. Therefore, the currently performed PSAs cannot be considered to be realistic, since they do not correspond to historical evidence.
>
> 2. Following the requirements of balanced risk of plant for all release modes [ie. the 'Farmer Curve'. (See above)], one would expect the frequency for INES6 to be 10 times higher than for INES7 and for INES5 10 times higher than INES6 (see Figure 1). [The latter was corrected from 'for INES6 10 times higher than INES5' after reference to Figure 1]. But, based on historical evidence, in terms only of releases there have been no accidents corresponding to INES5 and INES6. Examining all the accidents and their progression it would appear that if core damage is not recovered timely in-vessel as was the case of the TMI2 accident, only INES7 releases occur because no further mitigation is possible by the design of the plants or recovery procedures.’
>
> ‘Risk from accidents with higher rating increases and exceeds the risk given by IAEA safety criteria...’ [49]

Above about INES 3.5, the actual probability of core melt increasingly exceeds that predicted by the safety analyses.

Perrow noted that:

> 'Nothing is perfect, no matter how hard people try to make things work, and in the industrial arena there will always be failures of design, components, or procedures. There will always be operator errors and unexpected environmental conditions'. 'Some complex systems with catastrophic potential are just too dangerous to exist, not because we do not want to make them safe, but because, as experience has shown, we simply cannot.' [50]

In the US Reactor Safety Study WASH-1400, the probability of core damage was put at 1 in 20,000 reactor-y. With about 440 operating reactors, this is 1 in 45 y, but with 1 at Three Mile Island, 1 at Chernobyl and 3 at Fukushima, it is now 1 in 8 y. [51]

The Asahi Shimbun reported:

> 'Nuclear safety advisers slam stress tests.
>
> Two advisers to Japan's nuclear safety agency have slammed stress tests being conducted on idle nuclear reactors, saying they do not guarantee the safety of the facilities and calling into question the impartiality of the U.N. nuclear agency, which approved Japan's handling of the tests on Jan. 31. Masashi Goto, a former nuclear power plant designer, and Hiromitsu Ino, emeritus professor at the University of Tokyo, who both served as members of an advisory committee to Japan's Nuclear and Industrial Safety Agency (NISA) for the stress tests, said the International Atomic Energy Agency (IAEA) had sent a delegation to merely rubberstamp the process.
>
> At a news conference in Tokyo on Jan. 27, both Goto and Ino criticized the narrow scope of the test criteria and the lack of citizen involvement. "The calculations are all based on ideal scenarios: 'If this piece of equipment breaks, then will another kick in?'" said Ino. "It doesn't look at complex scenarios, such as system-wide failure due to the aging of the plant, or human error."
>
> The stress test model, which was imported from Europe, assesses the extent to which nuclear power plants can physically withstand "site-specific natural disasters"—namely, earthquakes and tsunami—and whether they have sufficient safety procedures in place to avoid power loss. The Japanese government announced last July that all the nation's nuclear plants would undergo the tests following the meltdown at the Fukushima No. 1 nuclear power plant caused by the magnitude-9.0 Great East Japan Earthquake earlier that year.
>
> All but three of Japan's 54 reactors are now offline, and must pass the stress tests as well as gain the approval of both local and national governments before they can be put back online. The tests do not assess aging of plant equipment or other potential causes of accidents, such as fires, plane crashes, tornadoes or lightning. According to Goto, even the scenarios for the two disasters the tests purport to simulate are insufficient. "The tsunami was not just an issue of water; there was rubble and boats flowing in, large amounts of fuel, fires out at sea—none of those factors were considered. Is it sufficient that a plant can withstand an earthquake 1.8 times stronger than that it was designed for? What happens if an earthquake twice as strong hits?" he said, referring to the magnitude used in a stress test simulation at the Oi nuclear power plant in Oi, Fukui Prefecture. Ino described the stress tests as an "optimistic desk simulation" in a written critique distributed at the conference. He argued that the tests will only be meaningful if they replicate the conditions at the Fukushima plant when the accident occurred. Although high radiation levels inside the plant are still impeding investigations into damage caused by the earthquake rather than the giant tsunami it spawned, Ino said water gauge readings taken from the pressure vessel suggests that the quake ruptured pipes, and that this should be reflected in the stress test criteria.
>
> Ino also voiced doubts about the impartiality of the IAEA, citing the organization's previous assessment of the Kashiwazaki-Kariwa nuclear power plant in Niigata Prefecture, following the 2007 Chuetsu-Oki earthquake, when the agency said the damage was less than expected without having any knowledge of the condition of the reactor pressure vessel or pipes. "It is highly unlikely that the IAEA can undertake a fair assessment. The agency promotes the nuclear industry and it is only investigating the stress tests for a short time", he said. "The last IAEA report was very flimsy, and I fear it'll be the same this time." '
>
> 'In his critique, Ino described a meeting of the advisory committee on Jan. 18 in which citizens were shut out and forced to watch the proceedings via a monitor from another room. "It is

inadmissible that the citizens' right to closely observe the review process was inhibited, the minimum requirements of democracy for such a crucial decision-making on whether or not to reopen nuclear power plants after a historic nuclear disaster," he wrote.

According to Goto, residents would be hard to please even if they were more involved in the process. "In reality what would make nuclear power really safe would be to make entire plants earthquake-proof, everything down to the wiring system," he said. "That's the viewpoint of the residents, and if you can't do it for financial reasons then I think they wouldn't want nuclear power at all." ' [52]

The Asahi Shimbun reported:

'Government puzzled by Madarame's remarks on stress tests.

Senior government officials are worried that a state panel set up to oversee the safety of nuclear facilities may get in the way of plans to restart suspended nuclear reactors to avoid power shortages this summer. Haruki Madarame, chairman of the Nuclear Safety Commission of Japan, established under the Cabinet Office, said on Feb. 20 that the first-stage "stress tests" at nuclear reactors were insufficient to determine their overall safety. "To assess the safety of nuclear facilities comprehensively, the results of the first-stage and second-stage (of stress tests) should be looked at together in one package," Madarame told a news conference. Under the first-stage tests, utilities have to look at how much of a safety cushion their reactors have against expected quake, tsunami and other disasters. The second-stage tests are much stricter and are designed to ensure through detailed inspections that Japan's nuclear facilities will be safe even in an accident that far exceeds expectations.' [53]

The Asahi Shimbun reported:

'Edano not banking on nuclear energy this summer.

Economy minister Yukio Edano said he does not expect any nuclear power plant to be operating this summer, but thermal power and conservation efforts should be enough for the nation to get by. In an interview with The Asahi Shimbun on Jan. 26, Edano said his ministry would compile measures by this spring on how to deal with a situation of zero nuclear power plants. Only four of the 54 nuclear reactors were operating as of Jan. 26. All four will stop operations by the end of April to undergo periodic inspections. Although the central government is considering allowing reactors to restart after electric power companies conduct stress tests to confirm their safety, the accident last year at the Fukushima No. 1 nuclear power plant has made obtaining the approval of local governments very difficult. "There is the possibility of no nuclear power plants operating (this summer)", Edano said, adding that it would be impossible to operate nuclear plants while placing less importance on safety.

Regarding the effects on the business sector in the absence of nuclear power plants, Edano said: "We will make the best effort to overcome the situation without affecting industry. There is that possibility if we make the effort." He said he was optimistic that Japan can handle the situation because of measures taken by electric power companies since last summer to increase electricity generation using thermal power plants and other alternatives to nuclear energy.' [54]

Although nuclear power accounted for about 30% of electricity generation in 2010, Japan managed to balance demand and supply after 2011-03-11 and could do so without nuclear power in 2012 and beyond. Such a phase-out would eliminate all the dangers of continued generation with nuclear power, including those from routine discharges.

In the US reports WASH-740 of 1957 and CRAC-2 of 1982, nuclear risk was expressed as the consequences of a 'maximum credible accident'. However in 1967, Farmer suggested that, for a given level of Risk in a 'balanced' design, the logarithm of the Consequence should be inversely related to the logarithm of the Probability. This became known as the 'Farmer curve' and interpreted as 'Risk = Consequence x Probability'. Yet regardless of the level of Risk, the Probability can never be zero, and while the Consequence can never be infinite, it can still be unacceptable. Even so, the Farmer curve has been used for risk assessment in all Reactor Safety Studies from WASH-1400 of 1975. This has had the effect – whether intended or not – of giving a false sense of security against unacceptable consequences.

The record shows that if an event reaches International Nuclear Event Scale INES 5, then it will almost certainly progress quickly to INES 7. Moreover, in severe accidents of INES 5 to 7, the contribution of human error is 100%. Above about INES 3.5, the actual probability of core melt increasingly exceeds that predicted by the safety analyses.

With three at Fukushima, the core melt frequency is now 1 in 8 years. Thus several would occur in the design life of a nuclear power plant, any one of which could be much worse than any so far. (See Section 11 below). Moreover, the danger depends very little on the safety of any new nuclear power plants, but very largely on that of the worldwide fleet of about 440 plants. As in the case of the Fukushima Daiichi Reactors 1 to 4, their ages are up to 40 years and more. [55]

The case against nuclear power depends ultimately on logic. As all engineers know, whatever can happen will happen - and invariably at the worst possible time. The probability of earthquakes or tsunamis is irrelevant. Even the anticipated accident sequences can number billions, so with the unanticipated, the probability of any radioactive release up to the maximum physically possible is unknowable. Hence this must be taken as 1 – i.e. inevitable. So Probabilistic Safety Analyses are misleading and inadequate due to human errors, deterioration, and logic. Thus the worst case - involving core meltdown(s) and the maximum physically possible release of radioactivity - and its consequences must be considered. (See Section 11 below). [56] By suggesting otherwise, the governments, national nuclear agencies, IAEA, and the nuclear power plant suppliers and operators are all guilty of deliberate deception.

Masashi Goto and Hiromitsu Ino, advisers to Japan's nuclear safety agency, say that the stress tests on the idle nuclear reactors do not guarantee their safety and call into question the impartiality of the IAEA, which approved Japan's handling of the tests on Jan. 31. Haruki Madarame, chairman of the Nuclear Safety Commission of Japan, established under the Cabinet Office, agrees and says that the results of the much-stricter second-stage tests - designed to ensure that Japan's nuclear facilities will be safe even in an accident that far exceeds expectations - should also be considered.

Ino also noted: "It is highly unlikely that the IAEA can undertake a fair assessment. The agency promotes the nuclear industry and it is only investigating the stress tests for a short time," he said. "The last IAEA report was very flimsy, and I fear it'll be the same this time."'

Economy minister Yukio Edano said he does not expect any nuclear power plant to be operating this summer, but thermal power and conservation efforts should be enough for the nation to get by. Such a phase-out would eliminate all the dangers of continued generation with nuclear power, including those from routine discharges.

3 RADIOACTIVE RELEASES

All radionuclides decay at rates measured as their half-lives - the time for the radioactivity to fall by one-half – and give off 'radioactivity' as alpha, beta and gamma radiation. Moreover, their activity and half-life are inversely related. [57] There are only a few 'primordial' radionuclides that have half-lives comparable to the age of the Earth. That of U-238 is about 4500 million years, the age of the Earth, and that of U-235 is about 700 million years, and due to decay now constitutes only 0.7% of natural uranium. The first life arose about 2100 million years ago, and the first humans around 3 million years ago. So when life arose and then humans evolved, only 'primordial' radionuclides were present, which now deliver an average effective dose external to the body of only about 0.3 mSv/y. [58]

Nuclear fuel usually consists of uranium, enriched to 3-4% U-235, clad in Zircaloy, an alloy of zirconium. This is true of the Fukushima Daiichi Reactors 1 to 3, save that Reactor 3 had some 6% of MOX fuel, containing some initial plutonium oxide. During nuclear fission, as energy is produced, fuel mass is lost and some of the uranium is transmuted to 'fission products', made up of over 100 different nuclides. Most are lighter than uranium, such as strontium, iodine and cesium, but some are heavier, such as plutonium. However, being artificial, with half-lives far shorter than the age of the Earth, they also have much higher activities, so are far more dangerous to all forms of life.

3.1 GASES AND VOLATILES

Nuclides	Xe-133	I-131	Cs-134	Cs-137
Melting Point - C	-111.9	113.5	28.5	28.5
Boiling Point - C	-108.1	184.0	678.4	678.4
Half Life	5.24 days	8 days	2.1 years	30.2 years
Alpha (particles)				
Beta (particles)	Y	Y	Y	Y
Gamma (rays)	Y	Y	Y	Y

Table 3: Properties of Some Gaseous and Volatile Nuclides

Most source term nuclides are radioactive and some are of special concern, because – as gases or volatiles (airborne aerosols) – they may be released by any breach of the fuel containments. The source terms depend on the type of release. 'The ratio of Sr-89/Cs-137 for a 'gap-release' (such as a pipe break) is 0, at (reactor) core-melt start is 2 and at (reactor pressure) vessel melt-through is 5'. [59]

3.2 STRONTIUM AND ACTINIDES

Nuclides	Sr-89	Sr-90	Pu-238	Pu-239	Pu-240	Pu-241	Np-239
Melting Point - C	769	769	641	641	641	641	637
Boiling Point - C	1384	1384	3232	3232	3232	3232	4000
Half Life	50.55 d	28.82 y	87.71 y	24,360 y	6560 y	14.35 y	2.35 d
Alpha (particles)			Y	Y	Y		
Beta (particles)	Y	Y				Y	Y
Gamma (rays)			weak	weak	weak	weak	

Table 4: Properties of Strontium and Some Actinides

At Fukushima, hydrogen explosions occurred, with off-site releases that included strontium and actinides, such as plutonium. Their presence proved that nuclear fuel melting had occurred.

3.3 BIOLOGICAL EFFECTS OF RADIOACTIVITY

Interviewed by Leslie Freeman, Dr John Gofman said:

‘Licensing a nuclear power plant is in my view, licensing random premeditated murder. First of all, when you license a plant, you know what you're doing--so it's premeditated. You can't say, “I didn't know.” Second, the evidence on radiation-producing cancer is beyond doubt. I've worked fifteen years on it [as of 1982], and so have many others. It is not a question any more: radiation produces cancer, and the evidence is good all the way down to the lowest doses.'

'Then I started hearing that there were a lot of people from the electric utility industry who were insulting us and our work. They were saying our cancer calculations from radiation were ridiculous, that they were poorly based scientifically, that there was plenty of evidence that we were wrong. Things like that. So I wondered what was going on there. At that point--January 1970--I hadn't said anything about nuclear power itself. In fact, I hadn't even thought about it. It was stupid not to have thought about it. I just wondered, Why is the electric utility industry attacking us? I began to look at all the ads that I had just cursorily seen in *Newsweek* and *Time* and *Life*, two-page spreads from the utilities, talking about their wonderful nuclear power program. And it was all going to be done “safely”, because they were never going to give radiation above the safe threshold. And I realized that the entire nuclear power program was based on a fraud--namely, that there was a *safe* amount of radiation, a permissible dose that wouldn't hurt anybody. ...’

Freeman added:

‘ “Someone from the AEC came to my house last weekend”, he said. “He lives near me. And he said, ‘We need you to help destroy Gofman and Tamplin’. And I told him you'd sent me a copy of your paper, and I didn't necessarily agree with every number you'd put in, but I didn't have any major difficulties with it either. It looked like sound science. And--you won't believe this--but do you know what he said to me? He said, ‘I don't care whether Gofman and Tamplin are right or not, scientifically. It's necessary to destroy them. The reason is’, he said, ‘by the time those people get the cancer and the leukemia, you'll be retired and I'll be retired, so what the hell difference does it make right now? We need our nuclear power program, and unless we destroy Gofman and Tamplin, the nuclear power program is in real hazard from what they say.’. . . . . . in 1972 the National Academy of Sciences published a report called the BEIR Report--Biological Effects of Ionizing Radiation--a long, thick report, in which they walked around the problem as best they could, and finally concluded that we were too high between four and ten times. But if you read the fine print, they were admitting that we might just be right.”[22]

When that came out, everybody realized that the AEC was not worth a damn. By then the AEC had gotten themselves into another flap. Henry Kendall and Dan Ford of the Union of Concerned Scientists showed that the AEC didn't know whether the Emergency Core Cooling System would ever work or wouldn't.[23] The Emergency Core Cooling System was the last barrier of safety in a major nuclear accident. This further damaged the credibility of the AEC. Those two events--the conflict with Ford and Kendall and the conflict with us--finally led them to realize they could no longer use the words *Atomic Energy Commission*, and so the government abolished the AEC. ‘We are now solving the problem’, they said. ‘We'll create two new agencies--ERDA (Energy Research and Development Agency) and NRC (Nuclear Regulatory Commission).’ ERDA was supposed to promote the development of atomic energy, and NRC was supposed to concern itself with public safety. The idea was that it was the promotion of nuclear energy that made the AEC's safety work so poor. The new NRC was only supposed to involve itself in safety--no promotion. Which turned out to be one of the greatest lies in history. . . . .’ [60]

RADNET includes the following entries:

‘Biologically Significant Radionuclides: radioactive substances such as plutonium, cesium, strontium, radioiodine, and tritium, etc. which provide the most significant health hazards to humans among all nuclides released from anthropogenic sources. Biological significance is a result of a combination of high decay energy, biogeochemical availability, efficient energy transfer to biological systems, and ubiquitous production during nuclear accidents and from industries.' '...biologically significant radionuclides are noted as indicator nuclides and are used to characterize inventories and pathways of nuclear effluents in the biosphere.

The biological significance of radiation results from the enormous amount of energy contained in each emission. Visible light has an energy range of 1.77 to 4.13 electron volts (ev). Most chemical changes occur within a range of 5 to 7 electron volts (ev). Biologically significant radiation levels range from 18,610 ev (0.01861 Mev) for the weak beta emitting tritium (1/2T = 12.346 yr.) to 511,630 ev (0.51163 Mev) for the ubiquitous cesium-137 (1/2T = 30.174 yr.) to 5,155,400 ev (5.1554 Mev) for the highly radiotoxic plutonium-239 (1/2T = 24,131 yr). These highly energetic emissions carry enough energy to tear electrons from neutral atoms and molecules. In delicate biological tissues, the impact of introducing radiation containing hundreds of thousands to millions of electron volts "can only be described as chemical and biological mayhem" (Gofman, 1981, p. 22). For example, the alpha radiation resulting from the decay of plutonium-239 has little penetrating power due to its large mass, but, if inhaled and deposited in the lung, is among the most radiotoxic of nuclides since its 5,155,000 ev (5.155 Mev) will be distributed within the area of only a few cells.

The weaker beta radiation of tritium (3H) is slightly more penetrating than alpha radiation; its biological significance comes from its ubiquitous production during the fission process, its tendency to follow the water cycle in nature, and its ability to become tissue bound in humans and the biotic environment. Cesium-137, a beta emitter with a gamma component, is biologically significant due to its energy level, its long half-life, its ubiquitous production during the fission process, and its tendency to follow the potassium cycle in nature, giving a whole body dose to those who ingest it.'

'Dose Conversion Factor: a factor (Sv/Bq or rem/Ci) that is multiplied by the intake quantity of a radionuclide (Bq or Ci) to estimate the committed dose equivalent from radiation (Sv or rem). The dose conversion factor depends on the route of entry (inhalation or ingestion), the lung clearance class (D, W or Y) for inhalation, the fractional uptake from the small intestine to blood (f1) for ingestion, and the organ of interest. EPA provides separate dose conversion factor tables for inhalation and ingestion, and each provides factors for the gonads, breast, lung, red marrow, bone surface, thyroid, remainder, and effective whole body. (Toxicological Profile for Ionizing Radiation, pg. 309).'

'Linear Energy Transfer (LET): Another key concept in determining biological effectiveness and significance, LET expresses the combination of charge and speed in effecting the efficiency of ionizing radiation. LET describes "the amount of energy transferred per unit of path traveled by the ionizing particle (electron, alpha particle or other)" (Gofman, 1981, p. 28). Alpha particles have twice the charge of a beta particle and, therefore, four times the efficiency of ionizing radiation per collision. Alpha radiation is much slower than beta or gamma radiation; therefore, it is much more efficient than the faster radiation, causing more ionizations per millimeter of distance traveled (See Gofman, p. 26-28). The efficient LET of alpha isotopes such as 239Pu combine with their high decay energies to form the basis of their biological effectiveness. High radiotoxicity and great biological significance accompany these long-lived anthropogenic radionuclides in the environment.' [61]

Busby stated:

'The exposure to radiation of the people of Fukushima should be calculated by establishing their external and internal exposures. The calculation of external extra dose is fairly straightforward since the mean external excess dose rates were known'. 'To assess internal exposure, the authorities measure Cs-134, Cs-137 and I-131. The internal doses are then calculated from inhalation and ingestion models using the ICRP (International Commission on Radiation Protection) dose coefficients. The reason that Caesium and Iodine nuclides are employed is that it is relatively easy to measure them since they have strong gamma signals'. (Compared with the ICRP values, the ECRR (European Committee on Radiation Risk) values for Te-132 are about 20 x, those for Sr-90 about 60 x, and those for U-238, 75 x or more). 'It is clear that dose coefficients are much greater for other nuclides emitted from the plant, notably the alpha emitters Uranium and Plutonium and the Strontiums than they are for the Caesiums.' [62]

Freeman quoted Gofman: 'Licensing a nuclear power plant is in my view, licensing random premeditated murder'. 'And I realized that the entire nuclear power program was based on a fraud--namely, that there was a *safe* amount of radiation, a permissible dose that wouldn't hurt anybody'. 'The new NRC was only supposed to involve itself in safety--no promotion. Which turned out to be one of the greatest lies in history. . . .'.

The energies of biologically significant levels of radiation are typically one million times those of chemical changes. These highly energetic emissions carry enough energy to tear electrons from neutral atoms and molecules. This can cause cancers and, by damaging DNA, also affect subsequent generations.

Strontium and actinides such as U-238 contribute to internal exposures, very strongly with the ECRR dose-effect model. So while the nuclides I-131, Cs-134, and Cs-137 are of great concern, others such as Sr-89 and Sr-90 and actinides, such as Pu-238, Pu-239, Pu-240 and Pu-241 and Np-239, are highly dangerous, especially if ingested or inhaled. Strontium can substitute for calcium and be retained in the bones and some actinides emit alpha particles. Both can cause cancer.

4 MEASUREMENTS OF RADIOACTIVITY FROM FUKUSHIMA

Measurements of radioactivity may be used with plume models to estimate the source terms of the release, the ground deposition and the dose to humans. Releases contain many nuclides, of which the activity declines with time, characterised by their half-lives, but these vary widely. Also their attributes - alpha, beta, gamma, X-rays and neutrons – differ, as do the sensitivities of instruments to them. So measurements repeated at different times will decline – albeit at a rate that can be calculated from the above.

Of the radioactive attributes - alpha, beta, gamma, X-rays and neutrons - most simple instruments can measure only gamma radiation. [63] [64] By assuming the Quality Factor as 1, they measure the absorbed dose rate – in Greys/time – but display it as the (human) dose equivalent rate – in Sieverts/time. However, this is true only for gamma radiation. [65] Therefore most reports give only dose values for the gamma emitters Iodine (131) and Cesium (134 and 137) and fail to mention that these are only indicative of the complete release. Moreover, the accuracy may be only +/- 50%. [66] To identify and quantify all the nuclides that may be present requires further measurement and analysis. [67] Measurements of radioactivity inside the human body require more elaborate equipment, such as whole body counters. [68]

4.1 GROUND-BASED MEASUREMENTS

Measurements of radioactivity may come from fixed stations, including those around the Fukushima Daiichi site [69] and the CTBTO worldwide network of radioactivity monitoring stations. [70] [71]

4.2 AERIAL SURVEYS

The air concentration and ground deposition of radioactivity may be determined by aerial survey. However, the Japanese authorities had no instrument at hand for airborne radioactivity measurements and the first aerial surveys were carried out in over 40 hours between March 17 and 19 by the Japan-based US Emergency Response Centers, with the results being made available via the US DOE website. [72] The dose equivalent of 11.9 to 125 microSieverts/hour (i.e. 104 to 1095 mSv/y) extended about 40 km to the north-west. Joint monitoring by the Japanese and the US - creditted as MEXT (Japanese Science Ministry) and the DOE (Department of Energy) - began on March 25. [73] The aerial survey flights started close to the Fukushima Daiichi site – from 3 to 40 km and from 40 to 80 km - and then were added to progressively – by prefecture – to cover most of mid-Japan (Honshu). [74] From the aerial gamma radiation (air dose) results were derived the ground depositions of Cs-134+Cs-137, Cs-134 and Cs-137. The first results from MEXT and DOE, dated 2011-05-06, include maps showing Fukushima prefecture, with the air dose and the ground depositions of Cs-134 + Cs-137, Cs-134 and Cs-137. [75] The results dated 2011-11-25 include maps showing Tokyo and 21 other prefectures, with the air dose and the ground depositions of Cs-134 + Cs-137, Cs-134 and Cs-137. [76] [77]

> Although Japan has installed and operated nuclear power plants capable of major radioactive releases for over 40 years, the Japanese authorities had no instrument at hand for airborne radioactivity measurements. This was gross negligence. Instead they had to rely initially on aerial surveys carried out by the Japan-based US Emergency Response Centers.

4.3 SOIL SAMPLING FOR IODINE AND CESIUM

Kinoshita et al reported:

> 'Radioactive iodine, strontium, and cesium, which have large fission yields and low boiling points, present a large risk for internal radiation exposure via ingestion of contaminated agricultural crops. These predictions also require an estimation of the emission inventory as well as knowledge of the distributions of various radionuclides and their transport and deposition on the ground. Therefore, we carried out gamma-ray spectrometry of surface soil samples collected in central-east Japan to contribute to this scientific enterprise.' [78]

> Kinoshita et al reported: 'Radioactive iodine, strontium, and cesium, which have large fission yields and low boiling points, present a large risk for internal radiation exposure via ingestion of contaminated agricultural crops'.

4.4 SOIL SAMPLING FOR STRONTIUM AND ACTINIDES

NHK reported that:

> 'Soil samples from around Fukushima Prefecture have revealed concentrations of radioactive strontium. Japan's science ministry conducted a survey for radioactive substances at 11 locations in 10 municipalities from late March to mid-May. It says strontium-90 was detected in all 11 locations. In Namie Town, the reading stood at 250 becquerels per kilogram of soil, while in Iitate Village the reading was 120 becquerels per kilogram. The readings in the other locations were between 2 and 18 becquerels.
>
> Strontium-90 is generated during the fission of uranium in fuel rods in reactors. With a comparatively long half-life of 29 years, the radioactive substance poses a risk of accumulating in the bones if inhaled, because its properties are similar to those of calcium. If this happens, it could cause cancer.' [79]

MEXT reported:

> '○ Soil samples for this survey were collected at places with a certain space free from disturbance. Although the monitored points were limited, we were able to ascertain the distribution of plutonium 238 and 239+240, and strontium 89 and 90 in the area within 80 km from the Fukushima Dai-ichi NPP.'
>
> '*1: These points are located in the restricted areas and planned evacuation areas, in which nobody resides at present.'
>
> (Reference 1)
>
> '• Accumulated effective doses for 50 years at points where the largest deposition amounts of plutonium 238 and 239+240, and strontium 89 and 90 were detected in this survey
>
> (i) Plutonium 238 : 0.027 mSv
>
> (ii) Plutonium 239+240 : 0.12 mSv
>
> (iii) Strontium 89 : 0.61 μSv (0.00061 mSv)
>
> (iv) Strontium 90 : 0.12 mSv

(Reference 2)

● Accumulated effective doses for 50 years at points where the largest deposition amounts of cesium 134 and 137 were detected in this survey

(v) Cesium 134 : 71 mSv

(vi) Cesium 137 : 2.0 Sv (2,000 mSv)

○ Compared with the accumulated effective doses for 50 years of cesium 134 and 137, those of plutonium and radioactive strontium were very small. Therefore, when assessing exposure doses or implementing decontamination measures in the future, we should focus attention on deposition amounts of cesium 134 and 137.'

The MEXT report included two maps of the results: 'Where Pu-238 and Pu-239+240 are considered to have been newly deposited due to the accident at the Fukushima Daiichi NPP' and 'Where Sr-89 and Sr-90 are considered to have been newly deposited due to the accident at the Fukushima Daiichi NPP (nuclear power plant)'. [80]

5 ESTIMATING SOURCE TERMS OF THE RELEASES FROM FUKUSHIMA

5.1 AIR-BORNE SOURCE TERMS FOR GASES AND VOLATILES

Vitazkova and Cazzoli noted:

'A range of possible atmospheric source terms is estimated, using three methods: dosimetric measurements at the plant, simplified accident progression, and aerial USDOE maps of surface contamination.' [81]

The first uses measurements made in the stack of the nuclear power plant, which is assumed not to be bypassed by damage.

The second is based on the radioactive inventory in the reactors and spent fuel pools and the damage to the fuel rods - estimated from the hydrogen produced. Using this 'direct' method, El-Jaby reported the source terms for: 'Cs-137, 3.48E+17 Bq, I-131, 1.33E+18 Bq'. [82]

The third uses measurements of radioactive concentrations and depositions on- and off-site. This is by considering a unit source of a given nuclide and using plume modelling to predict the concentration and deposition patterns. The unit source may then be scaled as necessary to align with the measurements for the same nuclide. This may be repeated for all the nuclides of concern – usually I-131, Cs-134 and Cs-137 – to give the source terms. The procedure is known as 'reverse estimation'. [83]

Wotawa reported on 2011-03-23:

'Regarding Iodine-131, the ...total 4-day emission ...(is) 4 10^17 (4E17) Bq'. 'Regarding Cesium-137, ... the source terms would be about 3 10^15 (3E15) Bq during the first two days, and 3 10^16 (3E16) during the second two-day period.' [84]

IRSN reported on 2011-03-22 the releases of the radioactive elements with the most significant radiological consequences, using proportions usually encountered in irradiated fuel. Rare gases were 2E18 Bq., Iodine 2E17 Bq., Cesium 3E16 Bq., and Tellurium 9E16 Bq. [85]

Michel gave estimated values for the total inventory (units 1 to 4) as I-131: 5E18, Cs-134: 2E18, and Cs-137: 2E18 Bq and quoted IRSN, 22.3.2011 for source terms Xe-133: 2E18, I-131 9E16, Cs-134: 1E16, and Cs-137: 1E16 Bq'. [86]

Nuclide	I-131	Cs-134	Cs-137
Inventory (units 1-4) - Bq	5E18	2E18	2E18
Released (source term) - Bq	9E16	1E16	1E16
Released/Inventory - %	1.8	0.5	0.5

Table 5: Estimates of the Fuel Inventory and Release Source Terms for Fukushima.

Wotawa reported on 2011-04-01, that:

> '..the sum of Iodine-131 emitted during the first week in Fukushima is between 1016 and 7 1017 (1E16 and 7E17) Bq. The sum of Caesium-137 is between 1015 and 7 1016 (1E15 and 7E16) Bq.' [87]

Michel quoted:

> 'NISA, 12.4.2011: I-131 1.3E17 Bq, Cs-137: 6.1E15 Bq' and 'NSC, 12.4.2011: I-131 1.5E17 Bq, Cs-137: 1.2E16 Bq.' [88]

Chino et al reported:

> 'According to Eq. (2), the total amounts of 131 I and 137 Cs discharged into the atmosphere from 10 JST on March 12 to 0 JST on April 6 are estimated to be approximately 1.5 1017 and 1.3 1016 Bq, respectively.' [89]

The Karlsruher Institut fuer Technologie reported the GRS estimated source term as Cs-134 of 1.0E16, Cs-137 of 1.0E16 and I-131 of 2.0E17 Bq. [90]

Morino et al reported:

> 'We simulated the deposition of I-131 and Cs-137 from Fukushima in March 2011. The model reproduced observed deposition rates over 15 Japanese prefectures. About 13% of I-131 and 22% of Cs-137 were deposited over land in Japan'.

Table 1 shows the emission (source term) for I-131 as 1.42E17 and Cs-137 as 9.94E15 Bq. Fig. 3 shows plots of the 'Model' versus the 'Observed' values of deposition for I-131 and Cs-137. [91]

Sugata et al reported more on the work of Morino et al, including the methodology and results. [92]

Scheuermann et al reported that:

> 'Released activity used in the calculation: Iodine gas 3.1E17 Bq., Aerosol gas (taken as Cesium) 1.9E17 Bq.' [93]

Skomorowski et al reported that:

> ‘Based on the model simulations and the available CTBTO (Comprehensive Test Ban Treaty Organization) measurements, ZAMG was the first institution world-wide that estimated a release rate of 131I and 137Cs. The estimate amounted to about 4*1017 Bq for 131I and 4*1016 Bq for 137Cs (ZAMG, 2011). Similar release rates were reported by the French Radiation Protection Institute a few hours later (IRSN, 2011) and later on by the Japan Nuclear Safety Commission and Japan Atomic Energy Agency (Chino et al., 2011).’ [94]

Stohl et al reported:

> ‘Regarding 133Xe, we find a total release of 16.7 (uncertainty range 13.4–20.0) EBq [16.7E18 Bq], which is the largest radioactive noble gas release in history not associated with nuclear bomb testing. There is strong evidence that the first strong 133Xe release started very early, possibly immediately after the earthquake and the emergency shutdown on 11 March at 06:00UTC. The entire noble gas inventory of reactor units 1–3 was set free into the atmosphere between 11 and 15 March 2011. For 137Cs, the inversion results give a total emission of 35.8 (23.3–50.1) PBq [35.8E15 Bq], or about 42% of the estimated Chernobyl emission’. [95]

Date	Author	Organization	Model	Xe-133	I-131	Cs-134	Cs-137
2011-03-22	Wotawa, G.	ZAMG, Austria	FLEXPART		4E17		3.3E16
2011-03-22		IRSN, France		2E18	2E17	1E16	3E16
2011-04-01	Wotawa, G.	ZAMG, Austria	FLEXPART		1E16 - 7E17		1E15 - 7E16
2011-04-12		NISA, Japan			1.3E17		6.1E15
2011-04-12		NSC, Japan			1.5E17		1.2E16
2011-05-02	Chino et al	JAEA, Japan	SPEEDI		1.5E17		1.3E16
2011-06-25		GRS, Germany			2.0E17	1.0E16	1.0E16
2011-08-02	Morino et al	NIES, Japan	CMAQ		1.42E17		9.94E15
2011-08-10	El-Jaby, A.	CNSC, Canada			1.33E18		3.48E17
2011-10-02	Scheuermann et al	IKE, Germany	ABR		3.1E17	1.9E17	
2011-10-02	Skomorowski et al	ZAMG, Austria	FLEXPART		4E17		4E16
2011-10-20	Stohl et al	(Multiple)	FLEXPART	1.34 - 2.0E19			2.33 - 5.0E16

Table 6: Estimated Release Source Term Amounts for Gases and Volatiles from Fukushima.

Almost all the results were obtained by reverse estimation, from plume models and (air) dose or ground deposition readings. Despite the difficulty of determining the source terms, particularly early on from limited data, these are notably consistent, with (mid-)values for I-131 and Cs-137 within factors of about 3. Only the CNSC (Canadian Nuclear Safety Commission) estimates were direct, from the nuclear fuel inventory and the core damage. Relative to the others, these values are about 10 times as high.

Releases are usually quantified with the Iodines, mainly I-131, which has a half-life of 8 days. On the International Nuclear Event Scale (INES), 5 implies a radiological release equivalent to I-131 of several times E14 Bq, 6 of several times E15 Bq and 7 of several times E16 Bq. [96] However, actual releases include source terms of other nuclides.

> It is noteworthy that Wotawa was the first to publish an estimate of the source terms. He leads a group of full-time professionals who are conversant with plume modelling and have access to data from the CTBTO worldwide network. This is what it takes to get rapid results, which are vital when so many lives and livelihoods are at stake.
>
> The source term values obtained by reverse estimation are notably consistent, with Chino et al's values for I-131 of 1.5E17 Bq and Cs-137 of 1.3E16 Bq, and the others within factors of about 3.

Michel estimated the total radioactive inventory for units 1 to 4, of which the IRSN values of the releases were - I-131: 1.8%, Cs-134: 0.5% and Cs-137: 0.5%. This shows that they could be very much higher. (See Section 11 below).

5.2 AIR-BORNE SOURCE TERMS FOR STRONTIUM AND ACTINIDES

There is a one-page article on the emissions of Plutonium and Neptunium from Fukushima, based on data from TEPCO. [97] It includes a table with, for four unequal time slots, the Total Emissions of Pu-239 and Np-239 as percentages and values in Bequerels. For the first 100 h, Pu-238, Pu-239, Pu-240, and Pu-241 together was 1.2 trillion Bq, and Np-239 was 76 trillion Bq. The two maps of Japan show the total concentrations of Pu-239 and Np-239 respectively. These show that all the Pu-239 and almost all the Np-239 were carried over the ocean. [98]

According to the MEXT report, the accumulated effective dose for 50 years at points where the largest deposition amounts of strontium 90 was detected would be only about 0.12 mSv. (See Section 4.4). The Dose Conversion Factor for internal exposure of Sr-90 according to the ECRR model is about 60 times that according to the ICRP model. [99]. However, this would still be only about 7 mSv, compared with the largest amounts detected of Cs-134 at 71 mSv and Cs-137 at 2000 mSv. Also almost all the Np-239 and Pu-239 have been carried over the ocean.

5.3 SOURCE TERMS FOR THE SEA

Nuclear Engineering International reported:

‘TEPCO has also issued a report about the three releases of radioactive water into the sea at Fukushima Daiichi. The first, 1-6 April, was a leak from the unit 2 turbine building. The 500 m3 of leaked water contained a total of 4.7x10^15 Bq of I-131, Cs-134 and Cs-137. Based on recently-measured radioactivity concentrations, 99.9% of this leak discharged out of the port by 9 May.

The second was an intentional discharge of 10,393 m3 of low-level radiation water from the central radioactive waste disposal facility, 4-10 April, to make way for more highly-contaminated water. Total radioactivity was 1.5x10^11 Bq of I-131, Cs-134 and Cs-137. That water was also judged to have left the port.

As a result of these leaks, a peak was noticeable at measuring points even 30km (18.6 miles) offshore during April (maximum: 186 Bq/L Cs-137), although most readings fell below measurable limits (10 Bq/L) in early May. Diffusion simulations suggest that the discharged water is likely to diffuse along the coast in a southerly direction, and then turn to the east from the Black Stream current.

The third leak was 250 m3 of highly contaminated water from the unit 3 turbine building 10-11 May. The total amount of radiation of I-131, Cs-134 and Cs-137 was estimated to be 2x10^15 Bq. Silt fences and other countermeasures have kept this water in the port area.’ [100]

Thus the total of I-131, Cs-134 and Cs-137 source terms in radioactive water released to the sea was 6.7E15 Bq.

Stohl et al reported that for Cs-137, the deposition was about 35.8 PBq (3.58E16 Bq), of which Japan 6.4 PBq – 19%, Other land 0.7 PBq – 2%, Over sea, balance – 79%. [101]

Thus the airborne Cs-137 source term that fell on the sea was 3.58E16 Bq x 0.79 = 2.8E16 Bq.

‘In an update of research done since their last report in July, France's nuclear monitor, the Institute for Radiological Protection and Nuclear Safety (IRSN), said on Wednesday that the amount of cesium 137 that leaked into the Pacific from the wrecked power plant was the “greatest single contamination by artifical radionuclides of the sea ever seen”. Their new assessment shows that the amount of cesium 137 that flowed into the Pacific after the disaster was probably nearly 30 times the amount stated by Tokyo Electric Power Company in May, reports Mainichi Japan. The IRSN estimate that the amount of cesium 137 that flowed into the sea from the power plant between 21 March and mid-July reached 27 peta (10 to the power of 15) becquerels. They also report that 82% of this contamination had reached the sea by 8 April. (1 Becquerel is one radioactive decay per second).' [102] [103]

This study found that the total Cs-137 source term via waterborne and airborne pathways was 2.7E16 Bq.

TEPCO reported that the radioactive I-131, Cs-134 and Cs-137 source terms released to the sea via water discharges, deliberate and not, was 6.7E15 Bq. Other studies found that the Cs-137 released via airborne fallout was 2.8E16 Bq and the total, via both waterborne and airborne pathways, was 2.7E16 Bq, about 4 times as much.

6 CONSEQUENCES OF THE RADIOACTIVE RELEASE FROM FUKUSHIMA

6.1 GROUND DEPOSITION AND DOSE TO HUMANS

The ground deposition and dose to humans may be estimated with plume models, together with measurements of radioactivity. As with the estimation of the source terms, some measurements of radioactivity were time-series from a few fixed stations, while others were spatially distributed, from aerial surveys and soil samples.

Isnard reported the estimation on about 2011-04-22 of the radioactive releases and use of atmospheric dispersion (plume) models to estimate the atmospheric air activity of I-131 and rainfall. He also reported the use of US DOE aerial survey dose rate measurements to estimate the distribution of the first year external dose to humans. [104]

Chino reported the use of SPEEDI with environmental monitoring data to model the plume and so estimate the source term. With WSPEEDI, it was also used to predict air concentration, ground deposition and radiological doses – both internal to the thyroid and external to the human body. [105] [106]

The Karlsruher Institut fuer Technologie used the GRS estimated source term with the RODOS plume model to estimate the ground deposition of Cs-137. The results were compared with the Aerial Measuring Results Joint US/Japan Survey Data as reported by the NNSA. The agreement of the distributions and the peak values was 'relatively good'. [107]

Vitázková & Cazzoli used several estimated source terms with the MACCS2 plume model to estimate the ground deposition, the dose to humans and the land area and number of people affected. [108]

Arnold et al used the source term of Chino et al with ARTM and RODOS to model the plume and estimate deposition values for Cs-134 and Cs-137. These agreed reasonably well with aero gamma measurements. [109]

Kinoshita et al used data from five soil sampling points and the HYSPLIT plume model to estimate the depositions of individual radionuclides of tellurium, iodine and cesium. [110]

Yasunari et al used the FLEXPART plume model and data on daily depositions of Cs-137 on Fukushima and surrounding prefectures, to estimate the total Cs-137 deposition and the spatial distribution. [111]

Date	Author	Organization	Plume Model	Ground Deposition	Human Dose
2011-04-22	Isnard, O.	IRSN	(Several)		Y
2011-04-25	Chino, M.	JAEA	SPEEDI/WSPEEDI	Y	Y
2011-06-25		KIT	RODOS	Y	
2011-09-05	Vitazkova & Cazzoli		MACCS2	Y	Y
2011-10-02	Arnold et al	GRS	ARTM & RODOS	Y	
2011-12-06	Kinoshita et al		HYSPLIT	Y	
2011-12-06	Yasunari et al		FLEXPART	Y	

Table 7: Plume Model Studies of Ground Depositions and Human Doses for Fukushima.

Several studies have used plume models of the radioactive release to estimate the spatial distribution of the ground deposition and of the doses that would be received by humans living there. Deposition and dose are usually quantified with the Cesiums, mainly Cs-134 and Cs-137, because they are longer-lived, with half-lives of 2 and 30 years. However, actual releases include source terms of other nuclides.

6.2 LAND AREA AND PEOPLE AFFECTED

The land area affected may be determined from the ground deposition distribution by applying a radioactivity criterion (in Bq/m2). The number of people affected may be determined either from the land area by estimating the population before evacuation or by estimating the population distribution and then applying a human dose criterion (in mSv/y).

The French Nuclear Safety Agency, IRSN, reported in the Executive Summary that:

> 'On the 56th day after the accident, MEXT published the first maps of caesium depositions. They revealed high values comparable with the most contaminated areas of Chernobyl, even beyond the initial 20 km-radius evacuation zone around the Fukushima plant. A new dose assessment was carried out by IRSN on the 66th day after the accident to estimate projected doses due to external exposure from radioactive deposits, for exposure durations of 3 months, 1 year and 4 years before evacuation.
>
> The estimated projected doses reach particularly significant values, some of them even above 200 mSv, which are no longer in the range of "low doses" according to UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) definition. Moreover these dose levels do not take into account neither the doses received from other pathways such as immersion within the plume and inhalation of particles in the plume during the accident nor the doses already received or to be received from ingestion of contaminated foodstuffs. The total effective doses to be received (external + internal) could be much higher according to the type of deposit (dry or wet), diet and source of food.
>
> The number of Japanese people living in the most contaminated areas outside the initial 20 km radius evacuation zone around the Fukushima plant (874 km2 with caesium 134+137 deposits higher than 600,000 Bq/m2) was estimated to 70,000 people including 9,500 children of 0-14 years in age.'
>
> 'The table on p 28 shows the Initial Evacuation Zone of 20 km radius to have an area of 628 km2, and a former population of 85,000. The 1st year External Dose is calculated from the Cs-137 deposits at 33 mSv per Million Bq/m2. For Cs-137 deposits of > 5E5 Bq/m2 and a 1st year External Dose of > 16 mSv, the total area is 1182 km2 and the total people affected 111,400. For Cs-137 deposits of > 3E5 Bq/m2 and a 1st year External Dose of > 10 mSv, the total area is 1502 km2 and the people affected 154,000.' [112]

The Mainichi Daily News reported:

> 'Soil contamination from Fukushima crisis comparable to Chernobyl: study.
>
> A massive soil decontamination project will be indispensable before residents in those areas can return," said Tomio Kawata, a research fellow of the Nuclear Waste Management Organization of Japan, at the meeting of the Japan Atomic Energy Commission, which sets policies and strategies for the government's nuclear power development. According to Kawata, soil in a 600 square kilometer area mostly to the northwest of the Fukushima plant is likely to have absorbed radioactive cesium of over 1.48 million becquerels per square meter, the yardstick for compulsory migration orders in the 1986 Chernobyl catastrophe. Kawata also said soil in a 700 square km area is likely to have absorbed 555,000-1.48 million becquerels per square meter, which was a criteria for temporary migration during the Chernobyl disaster. Kawata estimated the soil contamination using data on radiation levels in the air monitored by the Ministry of Education, Culture, Sports, Science and Technology. The size of the contaminated areas in the Fukushima crisis is one-tenth to one-fifth of those polluted in the Chernobyl disaster, Kawata said. While the expected radiation exposure from 1.48 million becquerels of cesium is around five millisieverts a year, below the government's benchmark of 20 millisieverts for evacuation orders, decontamination will still be necessary before evacuees can return as radioactive cesium binds strongly to soil, making it hard to reduce radiation levels, Kawata said.' [113]

Large and Associates reported that:

‘As for the public: over 200,000 individuals, some of them forcibly, have had to be evacuated from the Fukushima Prefecture to the north-east of the plant, about 3,200km2 of urban and arable land has been heavily contaminated, schoolchildren are now expected to tolerate a dose exposure of up to 20mSv. Confronted with all of this, the IAEA mission, headed by the UK’s Chief Nuclear Safety Inspector Mike Weightman, concluded, amongst other things, that the people evacuated will shortly be able to resume their normal lives. Nothing could be further from the truth’.[114]

Vitazkova and Cazzoli reported that:

‘..the annual yearly dose limit (obviously not enforced) for all ages is 1 mSv,...’ ‘From the information shown above it is estimated that about 260,000 people were evacuated within the first two months (to 20 km), and a further 120,000 should have been “relocated” after April 22nd, when the government “urged the population to leave selected areas”.’ [115]

The Asahi Shimbun reported:

‘An extensive area of more than 8,000 square kilometers has accumulated cesium 137 levels of 30,000 becquerels per square meter or more after the accident at the Fukushima No. 1 nuclear power plant, according to Asahi Shimbun estimates. 'The Asahi Shimbun calculated the size of the contaminated area based on a distribution map of accumulated cesium 137 levels measured from aircraft, which was released by the science ministry on Sept 8.’ [116]

von Hippel estimated the contaminated area as very roughly 600 km2, and – for a larger area - the people affected as about 1 million, with cancer deaths of about 1000. [117]

According to Shepherd, the extent of the contaminated (>20 mSv/y) zone was 700-1000km^2 and roughly 70,000-150,000 people were displaced. [118]

AFP reported:

‘Some land in Japan too radioactive to farm: study.’

‘East Fukushima prefecture exceeded limit for rice-growing soils of 5000 Bq/kg but three neighbouring prefectures are below 25 Bq/kg.’ [119]

This refers to: Yasunari et al. 'Cesium-137 deposition and contamination of Japanese soils due to the Fukushima nuclear accident'. From the Abstract:

‘We show that 137Cs strongly contaminated the soils in large areas of eastern and northeastern Japan, whereas western Japan was sheltered by mountain ranges. The soils around Fukushima NPP and neighboring prefectures have been extensively contaminated with depositions of more than 100,000 and 10,000 MBq km−2, respectively.’ (1E5 and 1E4 Bq/m2) ‘According to our results, food production in eastern Fukushima prefecture is likely severely impaired by the 137Cs loads of more than 2,500 Bq kg−1 (upper limit of farming) and also partially impacted in neighboring provinces such as Iwate, Miyagi, Yamagata, Niigata, Tochigi, Ibaraki, and Chiba, where values of more than 250 Bq kg−1 cannot be excluded.’ [120]

The Economist reported:

> 'Recently the government said it needed to clear about 2,419 square kilometres of contaminated soil—an area larger than greater Tokyo—that received an annual radiation dose of at least five millisieverts, or over 0.5 microsieverts an hour. That covered an area far beyond the official 30km restriction zone (see map). Besides pressure- hosing urban areas, this would involve removing about 5cm of topsoil from local farms as well as all the dead leaves in caesium-laden forests.' [121]

The IAEA reported that:

> 'The remediation programme covers about 500 km2 where radiation dose levels are above 20 mSv/a and about 1300 km2 where radiation dose levels are between 5 mSv/a and 20 mSv/a.' [122]

The Australian Broadcasting Company reported that:

> 'Japan's science ministry says 8 per cent of the country's surface area has been contaminated by radiation from the crippled Fukushima nuclear plant.' 'It says more than 30,000 square kilometres of the country has been blanketed by radioactive caesium.' 'The ministry says most of the contamination was caused by four large plumes of radiation spewed out by the Fukushima nuclear plant in the first two weeks after meltdowns.' 'The government says some of the radioactive material fell with rain and snow, leaving the affected areas with accumulations of more than 10,000 becquerels of caesium per square metre.' [123]

Date	Author/Organization	Criterion Bq/m2	Land Area km2	Criterion mSv/y	People Affected
2011-05-23	IRSN	Cs-137 > 5E5	1182	> 16	111,400
2011-05-23	IRSN	Cs-137 > 3E5	1502	> 10	154,400
2011-05-25	Kawata, T.	Cs-137 > 1.48E6	600		
2011-05-25	Kawata, T.	Cs-137 > 5.5E5	1300		
2011-06-14	Large and Associates		3,200	> 20	> 200,000
2011-09-05	Vitazkova & Cazzoli			> 1	380,000
2011-09-14	MEXT, Asahi Shimbun	Cs-137 > 3E5	> 8000		
2011-09-19	von Hippel, F.	Cs-137 > 3.7E4			~ 1 million
2011-09-30	Shepherd, J.E.		700-1000	> 20	> 70,000 – 150,000
2011-09-05	Yasunari et al, AFP	Cs-137 > 1E4	See text		
2011-10-08	Japanese Govt		2419	> 5	
2011-11-15	Japanese Govt		500	> 20	
2011-11-15	Japanese Govt		1800	> 5	
2011-11-22	MEXT, ABC	Cesium > 1E4	30,000		

Table 8: Estimates of Land Areas Contaminated and People Affected by the Fukushima Disaster.

> In the various studies, both the land areas and the people affected vary widely, depending on the values of the criteria. The land areas vary inversely with the deposition criteria in Bq/m2. In most cases, the number of people affected vary inversely with the dose criterion in mSv/y, but some estimates are based on simple deposition models, or on other studies. Also those favouring low dose-effect models may choose high dose criteria values and vice-versa. In these studies of Fukushima, the highest estimates of the land area - at 30,000 km2 (8% of Japan) - and of the people affected - at about 1 million - are both very large.

6.3 PEOPLE EVACUATED

Significant contamination of land by radioactive deposition – fallout - means that people must be evacuated. As well as the external dose, they must avoid breathing in particles and consuming food and water from the area, since these can result in an internal dose from radioactivity retained in the body. After decontamination and/or the passage of time (decades), the radioactivity of the environment, food and water may be low enough to allow some evacuees to return.

Fig. 1 is a map of Fukushima prefecture from the aerial survey by MEXT and DOE, dated 2011-05-06, showing the deposition of Cs-137. [124] This confirmed the need for the existing evacuation area to 20 km but also showed the need for expanding the evacuation area to the north-west. The Japanese Government began this evacuation only on 2011-05-16. [125]

Michel noted:

> 'Evacuation of 80,000 people from the 20 km circle on March 12, 2011.' 'stay in-house 20 km - 30 km on March 12, 2011'. '„should consider leaving" 20 km – 30 km am 15.3.2011.' [126]

The JAIF 'Earthquake Report' noted that:

> 'About 1,800 people in the evacuation area near the Fukushima Daiichi nuclear power plant still remain in their homes, despite the deadline to leave by the end of Tuesday. The government had instructed about 10,000 residents in the evacuation area sprawling 5 municipalities outside the 20 kilometer no-entry zone around the plant, to evacuate by the end of May'. [127].

Fig. 2 shows the Restricted Area, Evacuation Area and Evacuation-Prepared Areas, as of 2011-08-03. [128]

Vitazkova and Cazzoli reported that:

> 'From the information shown above it is estimated that about 260,000 people were evacuated within the first two months (to 20 km), and a further 120,000 should have been "relocated" after April 22nd, when the government "urged the population to leave selected areas".' [129]

Large and Associates reported that:

> 'As for the public: over 200,000 individuals, some of them forcibly, have had to be evacuated from the Fukushima Prefecture to the north-east of the plant, about 3,200km2 of urban and arable land has been heavily contaminated, schoolchildren are now expected to tolerate a dose exposure of up to 20mSv. Confronted with all of this, the IAEA mission, headed by the UK's Chief Nuclear Safety Inspector Mike Weightman, concluded, amongst other things, that the people evacuated will shortly be able to resume their normal lives. Nothing could be further from the truth.' [130]

Reuters reported that:

> 'About 80,000 people were forced to leave their homes by the nuclear crisis'. They were quoted as asking: "Can we actually go back home? And if not, can you guarantee our livelihoods?" 'The company expects a total of 300,000 claims from businesses given that the impact of the radiation crisis has been so widespread.' [131]

Fig. 3 is a map of Tokyo and 21 other prefectures derived by Asahi Shimbun from the aerial survey by MEXT, dated 2011-11-25, showing the deposition of Cs-134 and Cs-137. [132] For the decontamination plan, the dose limit was set equal to the ICRP recommendation and the Japanese 'planned exposure' value for the general public, at 1 mSv/y. [133] [134] [135] At the IRSN scaling of 16.6 mSv/y per million Bq/m2 of Cs-134 + Cs-137, this corresponds to a deposition of 60,000 Bq/m2. [136]. The blue area with more than this deposition extends far beyond the Restricted Area and Evacuation Area (shown in Fig. 2). It includes much more of Fukushima prefecture and large parts of Tochigi and Gunma prefectures, reaching almost 250 km. So to reduce the health effects, the evacuation zones should be far larger and more people should evacuate.

> Although there was some voluntary evacuation, the number of people to be evacuated depends mainly on the value of the exposure criterion applied. The dose limit was a political judgement, set initially at 20 mSv/y. So the number of people evacuated – at about 80,000 – was far smaller than the largest estimate of those affected – at about 1 million. However, the dose limit for the decontamination plan was later set equal to the ICRP recommendation for the general public, at 1 mSv/y. So to reduce the health effects, the evacuation zones should be far larger and more people should evacuate.

6.4 ANIMALS LEFT BEHIND

Nathalie-Kyoko Stucky wrote:

> ‘ The Buddha of Fukushima’s Forbidden Zone: A Photo Essay.
>
> Mr. Matsumura is willing to live in a nuclear wasteland to take care of the 400 cows, 60 pigs, 30 fowls, 10 dogs, 100 cats and an ostrich that the nuclear meltdown left behind. He is the Buddha of The Forbidden Zone.’
>
> ‘This is the story of Naoto Matsumura, Tomioka City, Fukushima Prefecture, Japan–the last man standing in Fukushima’s Forbidden Zone. He will not leave; he risks an early death because his defiance of Tokyo Electric Power Company (TEPCO) and the government is his life now. He is not crazy and he is not going. He remains there to remind people of the human costs of nuclear accidents. He is the King of The Forbidden Zone; its protector. He is the caretaker or empty houses, a point of contact for those citizen who can’t return. He takes care of the animals, “the sentient beings”, that remain behind because no one else will. He is the Buddha of the forbidden zone.’
>
> ‘Since the nuclear accident, Naoto Matsumura refuses to leave his farm. At the age of 52, this farmer is physically in a good shape. In the city of Tomioka, Fukushima Prefecture, where he currently lives, there is no water and no electricity. “When I wake up in the morning, I take my dogs for a nice walk. I brushing my teeth. I do this for about twenty minutes. And then I try to think about what to do for the rest of my day”. Matsumura usually eats instant ramen, which are easy to prepare with a bit of boiled water. He drinks mineral water when he manages to find some. In summer, he took showers in the greenhouse, with the water from the river, which he boils with charcoal he finds here and there. The water from the river is radioactive. Before the nuclear accident, Matsumura used to fish at the river. Last summer, he did his laundry there. With a large smile on his face, Matsumura says: “I love fishing. The rivers and the sea here are full of fish, however I cannot eat them, because they contain too much cesium. The rain of cesium particles spread by the crippled Fukushima Number 1 power plant（福島原発第一）after the nuclear meltdown back in March has contaminated them.”
>
> Tomioka is a small town that stands between the Fukushima Number 1 and Number 2 power plants. It used to be a quiet little town on the Pacific coast of Japan, where 16,000 inhabitants lived before March 12. To this day, some elderly people have been coming and leaving, but there is only one citizen who has stayed and lived there continuously. Tomioka was been evacuated on the next day after the tsunami hit. The orders from the authorities were clear and simple: “Take the minimum amount of your possessions and get out.”
>
> The refugees from Fukushima (Tomioka) have abandoned their houses, their belongings, their cars, their pets, but they hoped to come back afterwards. The last people who were resisting the orders like Matsumura, felt they had to give up the fight. TEPCO, the private operator of the Fukushima nuclear power plant, after first denying any meltdowns later revised their statements to acknowledge the core of three reactors had melted down and that the “problem” might still be actually solved… after 30 years. Matsumura notes that “TEPCO and the Japanese government have never stopped lying, out of their good will, in order to avoid panic among the population. Such good intentions, of course.”.’
>
> ‘In May 2011, there were about 2000 living cows. Three moths ago, there were 400 of them. As for the cats and dogs, we are not really sure about the numbers anymore.’

‘One day in June, Matsumura made an unexpected encounter in Okuma, a neighborhood in Tomioka. He does not like to go there because the level of radiation is very high, one of the highest spots in the forbidden zone. In Okuma, the corpses have been abandoned because they were too radioactive to be given back to their families. In the middle of the street, there was an ostrich. She was the only survivor of the local farm, which used to keep thirty other ostriches.’

‘For Matsumura, when asked to speak on the subject of TEPCO, the operator of the power plant, he thinks they did not act with excessive moderation, but with apathy and indifference.

“The citizens of Fukushima protest very little. TEPCO took their houses, their land, the air and the water, and they accept it! No one was angry. Before the construction of the nuclear power plant, TEPCO said: ‘Problems will never occur, never’. Everyone has been cheated. I went myself to the headquarters of TEPCO in Tokyo to ask them for explanations. The only things that the leaders have been able to tell me is ‘sumimasen’ (we’re sorry). And the Japanese government has repeatedly announced during three months, that the radioactivity is not dangerous!”.’

‘At some point, Matsumura has accepted to take a whole body counter check of the situation inside his body (internal exposure). The doctors exclaimed: “You are a champion of radiation!” Matsumura does not wish to comment any further on this subject. When he speaks about his family, he speaks very freely: “My father is 80 years old, my grandmother lived until she was hundred years old, so I had the hope to live at least until I get to my eighties. With the radioactivity, I think I will live until my sixties, at best”.

“Tomioka, for me, is the most beautiful place in the world, there is the ocean, the mountains and the forest. Nothing will make me leave this soil, on which my family has been living on for five generations”.’ [137]

‘Naoto Matsumura, Tomioka City, Fukushima Prefecture, Japan–the last man standing in Fukushima’s Forbidden Zone. He will not leave; he risks an early death because his defiance of Tokyo Electric Power Company (TEPCO) and the government is his life now. He is not crazy and he is not going. He remains there to remind people of the human costs of nuclear accidents. He is the King of The Forbidden Zone; its protector. He is the caretaker or empty houses, a point of contact for those citizen who can’t return. He takes care of the animals, “the sentient beings”, that remain behind because no one else will’.

‘Matsumura notes that “TEPCO and the Japanese government have never stopped lying, out of their good will, in order to avoid panic among the population. Such good intentions, of course.”.’

6.5 DURATION OF LAND LOST AND PEOPLE EXCLUDED

The New York Times reported that:

‘Broad areas around the stricken Fukushima Daiichi nuclear plant could soon be declared uninhabitable, perhaps for decades, after a government survey found radioactive contamination that far exceeded safe levels, several major media outlets said Monday.

The formal announcement, expected from the government in coming days, would be the first official recognition that the March accident could force the long-term depopulation of communities near the plant, an eventuality that scientists and some officials have been warning about for months. Lawmakers said over the weekend — and major newspapers reported Monday — that Prime Minister Naoto Kan was planning to visit Fukushima Prefecture, where the plant is, as early as Saturday to break the news directly to residents. The affected communities are all within 12 miles of the plant, an area that was evacuated immediately after the accident.

The government is expected to tell many of these residents that they will not be permitted to return to their homes for an indefinite period. It will also begin drawing up plans for compensating them by, among other things, renting their now uninhabitable land. While it is unclear if the government would specify how long these living restrictions would remain in place, news reports indicated it could be decades. That has been the case for areas around the Chernobyl plant in Ukraine after its 1986 accident.’ [138]

Reuters reported that:

> 'Japan faces the daunting task of decontaminating large areas of land around the Fukushima Daiichi nuclear complex, which is still leaking low levels of radiation nearly six months after an earthquake and tsunami triggered a nuclear meltdown. In a meeting with local officials on Saturday, the government estimated it could take more than 20 years before residents could safely return to areas with current radiation readings of 200 millisieverts per year, and a decade for areas at 100 millisieverts per year. The estimates, which merely confirm what many experts have been saying for months, are based on the natural decline of radiation over time and do not account for the impact of decontamination steps such as removing affected soil.'
>
> 'The Japanese government unveiled guidelines this week with the aim of halving radiation in problem areas in two years, but for spots with very high readings it could take much longer to reach safe levels. "I can't deny the possibility that it could be a long time before people can return to and live in regions with high radiation levels", outgoing Prime Minister Naoto Kan was quoted by domestic media as telling Fukushima Governor Yuhei Sato.
>
> Japan has banned people from entering within 20 km (12 miles) of the Fukushima plant, located 240 km northeast of Tokyo. Around 80,000 people have been evacuated since the March 11 quake and tsunami and many are living in shelters or temporary homes. The government's announcement follows the release of data this week showing radiation readings in 35 spots in the evacuation zone above the 20 millisieverts per year level deemed safe by the government. The highest reading was 508 millisieverts (per year) in the town of Okuma, about 3 km from the nuclear plant.' [139]

The ABC reported that:

> 'Former special adviser says Japan "too scared" to tell people the truth about Fukushima future.'
>
> '[...] Former special adviser to Japan's prime minister and cabinet Kenichi Matsumoto has told the ABC that the government has known for months that many who live close to the Fukushima plant will not be able to return to their homes for 10 to 20 years because of contamination. [...] He says the government is simply too scared to tell Fukushima residents that they cannot return. [...] "The government should have conveyed the truth to the evacuees. But it felt scared; it feared telling the truth to the people." [...]' [140]

> The nuclear fallout from Fukushima includes Cs-137, which has a half-life of about 30 years. (See Table 3 above). So unless the contamination and dose to humans can be reduced by removal, it will take many decades to die away. Therefore, even with decontamination, a significant area of Japan will remain uninhabitable for 10 to 20 years or more.

7 HUMAN HEALTH EFFECTS FROM FUKUSHIMA

7.1 PROMPT HEALTH EFFECTS

Following nuclear disasters, the people most exposed - both in dose and time - are the workers at the plant. Many are temporary and are 'burned out' by working in radioactive areas until they have received a certain dose and then replaced. Hence they are most likely to suffer prompt health effects - cancers and deaths.

Paul Jobin wrote:

> 'Dying for TEPCO? Fukushima's Nuclear Contract Workers.
> Liquidators recruited by ads
>
> In the titanic struggle to bring to closure the dangerous situation at Fukushima Nuclear Plant No1, there are many signs that TEPCO is facing great difficulties in finding workers. At present, there

are nearly 700 people at the site. As in ordinary times, workers rotate so as to limit the cumulative dose of radiation inherent in maintenance and cleanup work at the nuclear site. But this time, the risks are greater, and the method of recruitment unusual.

Job offers come not from TEPCO but from Mizukami Kogyo, a company whose business is construction and cleaning maintenance. The description indicates only that the work is at a nuclear plant in Fukushima Prefecture. The job is specified as 3 hours per day at an hourly wage of 10,000 yen. There is no information about danger, only the suggestion to ask the employer for further details on food, lodging, transportation and insurance.

The life of contract workers at nuclear plants

Those who answer these offers may have little awareness of the dangers and they are likely to have few other job opportunities. $122 an hour is hardly a king's ransom given the risk of cancer from high radiation levels. But TEPCO and NISA keep diffusing their usual propaganda to minimize the radiation risks'.
On March 14th, the Ministry of Health and Labor raised the maximum dose for workers to 250 mSv a year, where previously it was set at 100 mSv over 5 years (either 20 mSv a year for five years or 50 mSv for 2 years, which is in itself a strange interpretation of the recommendations of the International Commission on Radiological Protection's guideline stipulating a maximum of 20 mSv a year. The letter that the Ministry sent the next day to the chiefs of Labor Bureaus (都道府県労働局) to inform them of the decision justifies it on the grounds of the state of emergency (やむを得ない緊急の場合), ignoring the safety of the workers. This could be a measure to avoid or limit the number of workers who would apply for compensation. Stated differently, it has the effect of legalizing illness and deaths from nuclear radiation, or at least the state's responsibility for them. Usually, in case of leukemia, a one year exposure to 5 mSV is sufficient to obtain occupational hazards compensation. The list of potential applicants could be very long in light of the number of workers already on the job, or who are likely to be recruited to dismantle the reactors. The project proposed by Toshiba to close down and safeguard the reactors would take at least 10 years. In short, the state's concern appears to be less the health of employees and more the cost of caring for nuclear victims.' [141]

NHK reported:

'Radiation exposure for 2 workers may exceed limit

Two workers at the troubled Fukushima Daiichi nuclear power plant may have been exposed to high levels of radiation exceeding the safety limit set by the government. If confirmed, these are the first cases of radiation exposure since the health ministry raised the limit in March following the accident.

Tokyo Electric Power Company said on Monday the 2 workers are men. One is in his 30s and the other in his 40s. Both worked at the control rooms of the Number 3 and 4 reactors, and elsewhere, after the accident broke out at the plant. TEPCO said a test conducted at an institute last Monday found 9,760

becquerels and 7,690 becquerels of radioactive iodine-131 in the workers' thyroids. This means they are likely suffering from internal radiation exposure after inhaling radioactive substances. These figures are more than tenfold the other workers. It was confirmed that the 2 contaminated workers have been exposed to external radiation of 74 and 89 millisieverts so far.

TEPCO said these combined readings suggest that the 2 may have been exposed to radiation levels exceeding the safety limit of 250 millisieverts set for emergency situations'. [142]

The JRC Fukushima Update dated 2011-06-14 quoted:

'(WNN) Tests of the two control room operators exposed to radiation have been carried out. One of the workers has received a total dose of 678 mSv (88 mSv external dose, and 590 mSv internal dose), while the second worker received a total dose of 643 mSv (103 mSv external dose and 540 mSv internal dose). None of them show currently health problems as a result of their exposure.' [143]

This statement is far from the whole truth, as any competent authority would know. Whether or not any workers show health problems, latent cancers can take 10 or even 50 years to appear, and about half would be lethal. (See Section 7.2 below). So TEPCO, the nuclear agencies and the government were all misleading the workers and the general public.

NHK reported:

> ‘Fukushima workers exposed to high radiation
>
> The operator of the damaged nuclear power plant in Fukushima has been slow in checking workers at the plant for internal exposure to radiation. TEPCO began internal check-ups on March 22nd, 11 days after the nuclear accident at the Fukushima Daiichi plant. To date, less than 40 percent of about 3,700 workers at the damaged Daiichi plant have received internal check-ups for radiation exposure.
>
> TEPCO says 2 workers may have been exposed to about 650 millisievert of radiation. The 2 had been at the plant since the March 11th earthquake and tsunami that caused the nuclear disaster, but had their first internal check-up in mid-April, more than a month later. TEPCO says 30 workers have been externally exposed to more than 100 millisievert of radiation. Two of them were exposed on March 24th while working with their feet soaked in radioactive water in the basement of the Number 3 reactor's turbine building. One was found to have been internally exposed to 240 millisievert and the other to 226 millisievert.’ [144]

NHK reported:

> ‘Growing exposure problems at Fukushima
>
> Six other workers at the Fukushima-1 plant may have received radiation doses above the allowable emergency level. TEPCO reported to the health ministry on Monday on the results of the latest checks of workers at the power plant.
>
> The ministry says the provisional amount of radiation exposure was up to 497 millisieverts for each of six TEPCO male employees. The maximum allowable dose was formerly 100 millisieverts, but it was raised to 250 millisievert after the crisis started. One of the men was working in the control center, while the other five were performing maintenance work. Six additional workers received doses of between 200 and 250 millisievert, and 88 were exposed to between 100 and 200 millisievert.
>
> In late May, two TEPCO employees on duty at Reactors No. 3 and 4 received doses more than twice the emergency limit'.[i.e. more than 500 mSv].’ [145]

The JAIF reported that:

> ‘TEPCO has been examining the radiation exposure of about 14,800 workers who worked at the Fukushima Dai-ichi NPS. Intermediate result of this examination as of 9/30 is as follows.
>
> 99 workers received more than 100mSv. (100-150mSv: 77 workers, 150-200mSv: 14 workers, 200-250mSv: 2 workers, 250mSv-: 6 workers)
>
> Definite exposure doses of 6 workers who received more than 250mSv are distributed from 309 to 678mSv.
>
> *The allowable emergency limit for radiation doses: 250mSv.’ [146]

The Canadian reported that:

> ‘Fukushima rescuer dies from internal radiation.’
> ‘Her friend was a member of the special rescue unit of the Fire Department (probably in Osaka) who was sent numerous times to the disaster-affected areas in Fukushima and Iwate for the

rescue effort. In July, he was found with internal radiation exposure, but he had to continue working. His employer kept sending him and his colleagues to the disaster area even after the internal radiation exposure was found in them. She says that they got sick and they had to quit. But that was after they were berated by their superior as "unpatriotic". Her friend died in 3 months after having been found with internal radiation exposure.' [147]

The Japan Times reported that:

'Ministry not keeping track.'
'The health ministry has not been keeping track of radiation that workers at the Fukushima No. 1 nuclear plant are exposed to while off-site or off duty, ministry officials said Saturday, prompting concerns that current systems to check exposure may be inadequate. The health ministry also doesn't check radiation doses that workers are exposed to during decontamination efforts around the wrecked No. 1 plant. The ministry currently only keeps track of radiation exposure for the plant's employees when they are engaged in work around the facility.' [148]

Following nuclear disasters, the people most exposed – both in dose and time - are the workers at the plant. Many are temporary and are 'burned out' by working in radioactive areas until they have received a certain dose and then replaced. Hence they are most likely to suffer prompt health effects – cancers and deaths.

Officials claimed that no workers showed health problems as a result of their exposure. However latent cancers can take 10 or even 50 years to appear, and about half would be lethal. (See Section 7.2 below). So TEPCO, the nuclear agencies and the government were all misleading the workers and the general public.

The authorities took advantage of the loyalty of firemen and sent them into high-risk areas with inadequate protection. Since many such rescuers have been involved, this death is likely to be followed by others.

Even though they are hired to be exposed to higher radiation, the temporary workers are treated far worse than TEPCO employees. Yet TEPCO should be fully aware of human rights and the capabilities of robots, so this is inexcusable.

7.2 LATENT HEALTH EFFECTS

Busby has estimated the health outcome of the Fukushima catastrophe using the ICRP, Tondel and ECRR risk models for the dose-effect relation. This last has been validated by several lines of evidence, including that from Chernobyl. It puts the number of excess cancers for the 10 million people living within 200 km of the Fukushima power plants as approximately 420,000 in the next 50 years, although immediate evacuation would reduce this significantly. (Of these, about half would die from the excess cancers, according to Busby). [149]

Cochran et al estimated:

'For the ten prefectures considered – the total excess cancers as 703.7 and the total excess cancer deaths as 353.5.' [150]

Turkenburg reported:

'(26 April 2011) First Rough Estimates of (Health) Effects for Japan.

● No death within weeks due to radiation; about 4 death due to other reasons.

● At present: Exposure to radiation of about 3,500 workers, about 99% of them to values below 100 mS(v), 1% between 100 and 250 mS(v), and maybe some above 250 mS(v).

● Radioactive contamination of an area of about 1,000 km2 to levels (that) may result in its long-term evacuation.

... 1,000 death among the radiological workers and people living in “contaminated areas” (above 37kBq/m2 of Cs-137) and about 1,000 death in the rest of Japan'.

'Fukushima workers exposed to high radiation

● The operator of the damaged nuclear power plant in Fukushima has been slow in checking workers at the plant for internal exposure to radiation. TEPCO began internal check-ups on March 22nd, 11 days after the nuclear accident at the Fukushima Daiichi plant.

● To date, less than 40 percent of about 3,700 workers at the damaged Daiichi plant have received internal check-ups for radiation exposure.

● TEPCO says 2 workers may have been exposed to about 650 millisievert of radiation. The 2 had been at the plant since the March 11th earthquake and tsunami that caused the nuclear disaster, but had their first internal check-up in mid-April, more than a month later.

● TEPCO says 30 workers have been externally exposed to more than 100 millisievert of radiation.

● Two of them were exposed on March 24th while working with their feet soaked in radioactive water in the basement of the Number 3 reactor's turbine building. One was found to have been internally exposed to 240 millisievert and the other to 226 millisievert.

Source: NHK, May 30, 2011 & June 10, 2011.

Growing exposure problems at Fukushima

● Six other workers at the Fukushima-1 plant may have received radiation doses above the allowable emergency level.

● TEPCO reported to the health ministry on Monday on the results of the latest checks of workers at the power plant.

● The ministry says the provisional amount of radiation exposure was up to 497 millisieverts for each of six TEPCO male employees. The maximum allowable dose was formerly 100 millisieverts, but it was raised to 250 millisievert after the crisis started.

● One of the men was working in the control center, while the other five were performing maintenance work.

● Six additional workers received doses of between 200 and 250 millisievert, and 88 were exposed to between 100 and 200 millisievert.

● In late May, two TEPCO employees on duty at Reactors No. 3 and 4 received doses more than twice the emergency limit.

● Source: NHK, Monday, June 13, 2011 20:57 +0900 (JST).’ [151]

Vitazkova and Cazzoli reported:

‘The results with respect to health effects show that within 80 years the number of victims of the Fukushima disaster can be expected to be AT LEAST in the range of 10,000 to 300,000 people in terms of deaths due to infectious diseases, cardiovascular diseases, genetic diseases, and cancers; and about the same number of sicknesses/syndromes needing prolonged hospitalization and health care are expected to occur. This estimates accounts only for the population already living at the time of the accident. A comparable number of excess deaths and sicknesses may be expected in the population that will be born in the period. In addition to these, more than 100,000 excess still-births and a comparable or larger number of excess children born with genetic deformations (e.g. Down syndrome) are expected, projecting the results of [48].’ [152]

By comparing Fukushima with Chernobyl, von Hippel estimated that the cancer deaths would be about 1000. [153]

Date	Author	Organization	Dose-Effect Model	Period	Excess Cancers	Excess Deaths
2011-03-30	Busby, C.	ECRR	ICRP	50 y	6158	3079
2011-03-30	Busby, C.	ECRR	Tondel	10 y	224,223	112,111
2011-03-30	Busby, C.	ECRR	ECRR	50 y	420,000	210,000
2011-05-26	Cochran, T.B. et al	NRDC	BEIR VII		700	350
2011-06-16	Turkenburg, W.	U. Utrecht				~ 2000
2011-09-05	Vitazkova & Cazzoli		1 death/person-Sv	80 y		10,000 to 300,000+
2011-09-19	von Hippel, F.		ICRP	life		1000

Table 9: Estimates of the Human Health Effects of Fukushima

Many nuclear reports and news items imply that the only health consequences are the 'prompt deaths and injuries' and fail to mention the (latent) excess cancers and resulting deaths that may appear only after 10, 50 or even 70 years. Even if workers escape prompt health effects, they are still liable to suffer latent health effects. Many studies estimate depositions and doses but stop short of estimating health effects. (See Section 6.2 above). Only the study by Vitazkova and Cazzoli used a plume model to estimate the deposition and dose, together with the population distribution before evacuation, a criterion to determine the number of people affected and evacuation assumptions, to estimate the human health effects. The other studies estimated the health effects with simple models or by comparison with other data, such as that from Chernobyl.

The human health effects vary widely, depending on the dose-effect model used. Thus the BEIR (Biological Effects of Ionizing Radiation) VII model implies 100s, the ICRP model implies 1000s, while the Tondel, ECRR and '1 death/person-Sv' models imply 100,000s of excess cancers and deaths. The BEIR and ICRP have adopted the lowest dose-effects in the literature, and ignored much low-dose data. [154] Moreover, release source terms can include up to 100 different nuclides, but only a few are normally considered, so any estimates of the human health effects must be low. In this case, the source terms of Sr and Pu seem to be very small. (See Section 5.2 above). Even so, these human health effects omit those of ingesting contaminated food and water. (See Section 8 below). Furthermore, radioactivity - especially inhaled alpha-particles - causes genetic damage, which will be manifest as still-births, deformities, cancers and premature deaths in future generations. Yet this contravenes the 'precautionary principle', which would be met by using the ECRR model. [155]

The evacuations should reduce these latent health effects, but if the Fukushima evacuees were to return before decontamination and/or decay of the radioactivity over decades, they would increase again. So the evacuees must be informed accordingly before any return is permitted, much less encouraged. (See Section 4.5 above).

Many quantitative studies of the Fukushima disaster and consequences – such as release source terms, ground deposition, human dose, land area, people affected and health effects - have been published (mostly in English) by individuals and organizations in many different countries. These include Austria, France, Germany, Japan, Netherlands, Switzerland and the USA. However, no proper studies have been found from the IAEA or the UK Office of Nuclear Regulation (ONR), which casts doubt on their readiness and ability to carry out such studies.

7.3 HEALTH CHECKS

NHK reported that:

‘Checking internal radiation of people begins.

An atomic energy research facility in Ibaraki Prefecture has begun screening residents from neighboring Fukushima in northeast Japan for internal radiation. Fukushima Prefecture plans to check its entire population of about 2 million to assess the effect of the accident at the Fukushima Daiichi nuclear plant. It is now checking internal radiation levels for residents in the evacuation zone and areas near the nuclear plant as well.

Similar checks have also begun at the government-affiliated Japan Atomic Energy Agency in Tokai Village, Ibaraki where a total 28 pregnant women, parents and their small children from Namie Town arrived on Tuesday. A piece of equipment called a Whole Body Counter will be used to determine if they have absorbed radioactive materials through food and drinks. The facility will examine about 2,800 people from Fukushima through next month.' [156]

The Telegraph reported that:

'Children in Fukushima to be given regular cancer tests.
Fukushima prefectural government plans to carry out regular ultrasound examinations on all residents who were 18 years old or under when the nuclear crisis broke out on March 11. The tests, designed to spot early symptoms of thyroid cancer, will be conducted every two years until the age of 20 and then every five years, according to Japanese news reports. An estimated 360,000 young residents will be entitled to the free medical tests, which will start operating from October this year, with further in-depth urine and blood testing taking places if any abnormalities are discovered.

News of the lifelong testing follows growing concern surrounding the potential health impact of the still stricken Fukushima nuclear power plant on residents in surrounding regions.' [157]

NHK reported:

'Radiation effect on children's thyroid glands.

[...] A group of researchers led by Hiroshima University professor Satoshi Tashiro tested 1,149 children in the prefecture for radiation in their thyroid glands in March following the accident at the Fukushima Daiichi nuclear plant. Radioactive iodine was detected in about half of the children. Tashiro says radiation in thyroid glands exceeding 100 millisieverts poses a threat to humans, but that the highest level in the survey was 35 millisieverts. [...]' [158]

The BBC reported that:

'Health officials hope to test some 360,000 people who were under 18 years old when the nuclear crisis began in March, and provide regular follow-up tests.' [159]

The Asahi Shimbun reported that:

'On the basis of estimated exposure levels, the prefectural government plans to conduct follow-up health surveys, which will cover all of the approximately 2 million residents, for at least 30 years.' [160]

The Fukushima prefectural government plans to test some 360,000 people who were under 18 on March 11 throughout their lives and all of the approximately 2 million residents for at least 30 years.

8 FOOD AND WATER CONTAMINATION FROM FUKUSHIMA

Many news reports mention the radioactivity entering the human food chain and the loss of livelihood for farmers and fisherfolk. However, very few mention that ingestion and inhalation add internal exposure to any external exposure.

Martin J. Frid wrote:

‘Food Safety: Addressing Radiation in Japan’s Northeast after 3.11

Japan had no guidance levels or restrictions for nuclear substances on food at the time of the nuclear disaster. It raced to draw up provisional regulation values by March 17 and legislation by March 29, 2011.

Japan’s Food Safety Commission (FSCJ) notes:

“Due to this radiation leakage, from the perspective of the Food Sanitation Act, which aims to prevent sanitation hazards resulting from eating and drinking, the ‘Indices relating to limits on food and drink ingestion’ indicated by the Nuclear Safety Commission of Japan was adopted for the time being as provisional regulation values. So the foods which exceed these levels are regulated to ensure those foods are not supplied to the public to eat, and local governments have been notified by the Ministry of Health, Labour and Welfare on 2011 March 17. This provisional regulation values [sic] were adopted without an assessment of the effect of food on health by FSCJ because of its urgency, therefore on 2011 March 20, the Minister of Health, Labour and Welfare requested FSCJ for an assessment of the effect of food on health.”

The safety levels in Japan are generally similar to values in other countries, and identical to those of the 26 member countries of the European Union. The exposure limit for Caesium-134 plus Caesium-137 in drinking water and milk is 200 Bq/kg in Japan and the EU, while the US has settled on a higher level (1,200 Bq/kg). Also, in foods such as vegetables, grains and meat, Japan and the EU has a limit of 500 Bq/kg while the US has a limit of 1,200 Bq/kg. Whether or not the public in Japan is exposed to levels above these limits is not clear at this point and needs to be investigated further.’ [161]

Foodwatch & IPPNW wrote:

‘Foodwatch and IPPNW believe that the European Union, the German government and the Japanese government do not do enough to inform their citizens that there are no “safe” maximum limits for the radioactive contamination of foodstuffs. Exposure to radiation, no matter how minimal, is a risk to health because it is enough to trigger major illnesses such as cancer. The setting of any permissible limits is equivalent to making a decision on the number of fatalities to be tolerated.’

‘Permissible limits today in the EU stand between 200 and 600 becquerels of cesium per kilogram of food. This is in stark contradiction to standards found in currently valid German legislation. The German Radiation Protection Ordinance governing the operation of nuclear power plants stipulates that total exposure for an individual may not exceed an effective annual dose of 1 mSv per year. In contrast, the EU radiation limits for foodstuffs tolerate an annual dose of at least 33 mSv for adults and 68 mSv for children and adolescents.’

‘Since there is enough food available which is far less radioactively contaminated, there is no need to expect people to eat highly contaminated products. For this reason, foodwatch and IPPNW are calling for a drastic lowering of the value limits from their present level of 370 becquerels (200 for imports from Japan) down to 8 becquerels of cesium per kilogram for baby food and milk products, and from the present level of 600 becquerels (currently 500 for imports from Japan) down to 16 becquerels of cesium per kilogram for all other foodstuffs.’

‘In calling for this change, we know full well that allowing any permissible limits at all means that a certain number of people will be victims of radiation. This should be reason enough to question the continuing operation or new construction of nuclear facilities.’

‘As a consequence of the Chernobyl nuclear disaster, the European Union set maximum limits on the level of radioactive contamination permitted in foodstuff imports from countries outside the EU; regarding total cesium radionuclides, these limits stand at 370 becquerels/kilogram for baby food and milk products and at 600 becquerels/kilogram for other foodstuffs. These limits also apply to food traded within the EU. In response to the Fukushima disaster, the EU provisionally set stricter permissible limits at 200 and 500 becquerels respectively for imports from Japan.’

‘3. Influence of commercial interests

• In an agreement made more than 50 years ago, the World Health Organization (WHO) relinquished jurisdiction to the International Atomic Energy Agency (IAEA) on defining the health damage caused by radiation. The declared aim of the IAEA is the expansion and promotion of nuclear energy. The International Commission on Radiological Protection (ICRP) and the European Atomic Energy Community (EURATOM) are dominated by the nuclear industry and radiologists.' [162]

The health effects are increased if radioactivity is ingested with food and drink - and especially if inhaled – causing additional, internal exposure. (See Section 3.1 above). Japan has had nuclear power plants for more than 40 years, yet had no guidance levels or restrictions for nuclear substances on food at the time of the Fukushima nuclear disaster. The reason for this is unknown, but is at least incompetence. That said, Europe did not develop such standards until the fallout from Chernobyl arrived in 1986. In both cases, the nuclear interests knew of the dangers, but failed to alert the politicians to the need for such standards, even though the criteria values would be political judgements. To comply with the current German radioactivity limits for food, the EU limits should be reduced by around 40-fold. However the World Health Organization (WHO) has relinquished jurisdiction to the IAEA, which like the ICRP and EURATOM (the European Atomic Energy Community), is dominated by the nuclear industry and their commercial interests.

8.1 LAND FOOD CONTAMINATION

NHK reported:

'Cesium found in hay at another farm in Fukushima.'

'Radioactive cesium far exceeding safe limits has been detected in hay fed to cattle at a second farm near the crippled nuclear power plant in Fukushima Prefecture. Fukushima's government warned on Thursday that 42 possibly contaminated cattle have already been shipped out from the farm in Asakawa Town. The finding came during inspections ordered by the prefecture after a large dose of the radioactive substance was found in hay at the first farm in Minami-Soma City. The latest checks uncovered radioactive cesium measured up to 97,000 becquerels per kilogram -- some 73 times the government-set safety limit. [of 1300 Bq/kg] The 42 cattle had been sent to 4 meat-processing plants between April 8th and July 6th -- 14 to Yokohama; 13 to Tokyo; 10 to Sendai and 5 to Chiba. The prefecture has ordered the farm to stop shipping and transporting its cattle. It has also provided detailed information to relevant municipalities, asking them to trace back distribution channels of beef from the cattle.' [163]

NHK reported:

'Govt to buy back beef with excessive cesium levels.

The Japanese government says it will buy back beef containing radioactive cesium that has already reached the distribution chain. The measure, announced on Tuesday, is designed to allay rising concerns about the safety of beef.

Consumers have been rattled by reports of cattle fed with rice straw containing cesium in excess of the government-mandated limit.

NHK has learned that more than 2,800 head of cattle allegedly fed with such straw have been shipped to 46 of Japan's 47 prefectures, excluding Okinawa. Excessive levels of cesium have been detected in beef in 6 of the prefectures, including Fukushima, where work continues to contain a nuclear plant accident. Some of the beef that reached the markets has yet to be tested. The government will seek inspections of all such beef, and buy the meat back if higher-than-permissible cesium is detected. The government plans to eventually pass on the buy-back costs to Tokyo Electric Power Company, the operator of the disabled nuclear plant.' [164]

NHK reported:

> ‘Govt to check rice for radiation' and 'Govt bans beef cattle shipments from Iwate.’ [165]

Reuters reported:

> ‘Concerns have grown over the safety of food supplies after a March 11 earthquake and tsunami crippled the Fukushima Daiichi nuclear plant, spreading radiation over a large swathe of northern and eastern Japan. Excessive levels of radiation have been found in vegetables, tea, milk, seafood and water. The government last month halted shipments of beef cattle from Miyagi and Fukushima after finding that livestock had eaten straw contaminated with radioactive cesium stemming from the leaks at the plant.
>
> “We have put in place steps for securing the safety (of cattle shipped from Miyagi)”, Chief Cabinet Secretary Yukio Edano told a news conference. “But this is only a partial lifting of the ban to allow shipments under a controlled environment.” Shipments from Miyagi will be allowed on condition that cattle are tested for radiation contamination, while the Miyagi prefectural government will be responsible for eliminating tainted feed, Edano said. As for cattle from Fukushima, the government needs to wait “a few more days” to decide whether to lift its ban, a farm ministry official said. The decision comes after beef from a cow shipped from Fukushima in April was found on Friday to contain radioactive cesium exceeding the government-imposed ceiling of 500 becquerels, the official said.’ [166]

AFP reported:

> ‘Japan bans Fukushima rice for radiation.’
> ‘Authorities in Fukushima prefecture say rice produced near the stricken atomic power plant contained caesium they measured at 630 becquerels per kilogram (2.2 pounds). The government safety limit is 500 becquerels. Chief Cabinet Secretary Osamu Fujimura ordered Fukushima Governor Yuhei Sato to restrict shipments of rice from Onami -- from where the samples were sourced -- according to an agricultural ministry official. “This restriction won't be lifted until safety of the rice produced in the area can be confirmed”, the official said, adding that the ban will affect 154 farms that produced 192 tonnes of rice this year.’ [167]

The Yomiuri Shimbun reported:

> ‘Suspect cattle still untested / Location of nearly 3,000 cows in radiation scare remains unknown.
>
> The Health, Labor and Welfare Ministry has been unable to track the distribution routes of nearly 3,000 cows whose meat is suspected to contain high levels of radioactive cesium, ministry officials said. The ministry wanted to inspect the meat of 4,626 beef cattle from 15 prefectures because it suspected the animals were fed rice straw contaminated by radioactive substances released at the outbreak of the crisis at the Fukushima No. 1 nuclear plant. The meat of 1,630 cows--about 35 percent--had been inspected as of Wednesday, but the ministry says the distribution routes of the remaining 2,996 animals remains unknown.’
>
> ‘Beef from the 4,626 cows is known to have been shipped from 15 prefectures spanning from Hokkaido to Shimane Prefecture. From July to October, the beef from 1,585 animals had been inspected, and meat from another 45 animals was tested in November, according to reports from prefectural governments. But there have been no inspections of beef from the remaining cattle. The results from the inspections show meat from 105 cattle in six prefectures--6.4 percent of the 1,630 animals tested--had radioactive cesium exceeding the government's provisional limit of 500 becquerels per kilogram. By prefecture, 54 of the 105 cows were bred in Miyagi and 21 were shipped from Fukushima. Iwate had 16, followed by Tochigi with 10. Two each were from Yamagata and Akita.’ [168]

The aerial and soil surveys give estimates of soil contamination but the food contamination is affected by Transfer Factors. Thus taking the limit for rice - as for all foodstuffs - as 500 Bq/kg, then – assuming that the Transfer Factor is 0.1 – the limit for soil for rice-growing is 5000 Bq/kg. However, the Transfer Factors may be very different for different foods. Moreover, the radioactive contamination can be increased in concentration in food chains – e.g. vegetable to animal. Yet the limit for fodder (e.g. rice straw) is 1300 Bq/kg, while that for meat (e.g. beef) is 500 Bq/kg – in line with international standards.

> The requirements for testing land foods for radioactivity are very considerable. They include staff, instruments and compensation for any that is rejected as over the limit. Moreover, this must continue for 10 to 20 years or more.

8.2 SEA FOOD CONTAMINATION

In the case of seafoods, seawater, silt and sea animals all move. Moreover, radioactivity is increased in concentration in marine food chains. For example, Cs-137 is increased by 30 to 50 times for various sea foods. [169]

The New York Times reported:

> 'On Tuesday, the government said that a fish caught about 43 miles away was found to have high levels of radioactive iodine 131, prompting it to announce radiation safety levels for fish.'
>
> 'The small fish caught Friday – before the intentional dumping [of radioactive water] began – had 4,080 bequerels of iodine 131 per kilogram. The new standards allow up to 2,000 bequerels of iodine 131 per kilogram, the standard used for vegetables in Japan, but it was unclear how the government would enforce the new rules.'
>
> 'The fish also contained cesium 137, which decays much more slowly than iodine 131, at a level of 526 bequerels per kilogram.' 'Fish and seaweed can concentrate radioactive elements as they grow, leading to levels that are higher, sometimes far higher, than in the surrounding water. Seaweed can concentrate iodine 131 10,000-fold over the surrounding water; fish concentrate cesium 137 modestly.' [170]

Turkenburg quoted:

> 'Excessive radioactive cesium found in fish caught off Fukushima'. (2011-04-13).
> Level was 25x standard.
>
> ● Radioactive cesium 25 times above the legal limit for consumption was detected Wednesday in young sand lance caught off Fukushima Prefecture, the Ministry of Health, Labor and Welfare said. One of the sample fish had a level of cesium of 12,500 becquerels per kilogram about 500 meters off the city of Iwaki, and 35 kilometers from the crippled Fukushima Daiichi nuclear power station, it said. The limit is 500 becquerels per kg under the Food Sanitation Law.'
>
> ● 'Japan's science ministry has detected extraordinarily high levels of radioactive cesium in seafloor samples collected off Miyagi and Ibaraki Prefectures.
>
> ● The ministry collected samples from 12 locations along a 300-kilometer stretch off Fukushima prefecture's Pacific coast between May 9th and 14th. It hoped to get an idea about the spread of nuclear contamination caused by the accident at the Fukushima Daiichi nuclear power plant.
>
> ● Radioactive substances were found in all locations, including those off Miyagi and Ibaraki Prefectures, which had not been previously investigated.
>
> ● Radioactive Cesium-137, measuring 110 becquerels per kilogram or about 100 times the normal level, was found in samples collected from the seabed 30 kilometers off Sendai City and 45 meters beneath the surface.
>
> NHK. 'Radioactive materials found off Miyagi and Ibaraki'. 2011-05-28.' [171]

Weiss reported the contamination of water, sediments and biota near Fukushima and concluded:

> ‘Activity values of radioactive cesium (Cs-134 and Cs-137) in fish in the vicinity of the NPP sometimes amounted to more than 1,000 Bq/kg, however measuring less than 10 Bq/kg radioactive cesium in the fishing grounds of Northern Pacific at the distance of some 100 km. In other seafood species from the coastal areas only sporadical total cesium contents of higher than 500 Bq/kg were measured.
>
> As the seaside setting of the Fukushima NPP is restricted up to about 30 km for fishing of seafood and seaweed, and while current Cs concentration values in water, sediments and fish measured at greater distance remaining inconspicuous, there is no danger for people to be posed by consumption of fish and seafood from those particular Pacific fishing grounds.’ [172]

> Since the radioactive half-life of Cs-137 is 30 years, and the radioactivity in sea foods is very hard to estimate, it is necessary to have comprehensive testing. The activity values of radioactive cesium (Cs-134 + Cs-137) in sea foods from the coastal areas now only rarely exceeds the limit of 500 Bq/kg while that in other species from fishing grounds some 100 km away measures less than 10 Bq/kg. Even so, the coastal fishing industry has been greatly damaged.

9 DECONTAMINATION AND RADIOACTIVE WASTE STORAGE AFTER FUKUSHIMA

9.1 DECONTAMINATION OF WATER, AND LIQUID RADIOACTIVE WASTE STORAGE

NHK reported:

> ‘Water levels are rising in the basements of the turbine buildings of reactors 3 and 4. The total amount of accumulated wastewater at the plant is now estimated at more than 105,000 tons. TEPCO plans to start filtering highly radioactive water on June 15th. It will treat 1,200 tons of water per day and transfer the filtered water to temporary tanks'. [173] Shepherd included photographs of the tanks.’ [174]

Large and Associates reported:

> ‘TEPCO managed to maintain the increasingly absurd line that the fuel cores had not melted and that the reactor containments were holding for two months into the accident. During that time, the 10,000 or so tonnes of highly contaminated water on the site increased to 100,000 tonnes presenting almost insurmountable storage capacity difficulties against which thousands of tonnes of so-called lightly radioactive water was sacrificially dumped into the marine environment.’ [175]

The Asahi Shimbun reported:

> ‘Fisheries cooperatives on Dec. 8 demanded Tokyo Electric Power Co. rescind its plan to release radioactive water from its crippled nuclear plant into the sea, saying the move would further damage their industry'. 'The company said it is running out of options because the nuclear complex has limited space for additional tanks that can store the water. The existing storage tanks at the plant now hold about 100,000 tons but are expected to be full in March. The water is being used to cool the damaged reactors in a recycling system that purifies the radioactive water and pumps it back into the reactors. But an estimated 400 tons of groundwater a day continues to flow into the plant. The company has considered recycling such water and stemming the inflow, as well as buying additional water-treatment equipment, but it has not come up with a solid plan.’ [176]

> Radioactive waste water will continue to accumulate until the reactor and fuel pool decay heat falls, reducing the cooling load, and the radioactive water cleanup plant throughput catches up with the water demand for cooling. Until then, fresh water must be supplied for 'once-through' cooling, and the resulting radioactive waste water would require ever more 'temporary' storage tanks and/or discharges to the sea.

9.2 DECONTAMINATION OF LAND, AND SOLID RADIOACTIVE WASTE STORAGE

The Economist provided a detailed impression of the many impacts of Fukushima:

> ‘Hot Spots and Blind Spots.
>
> Crest the hill into the village of Iitate, and the reading on a radiation dosimeter surges eightfold—even with the car windows shut. “Don’t worry, I’ve been coming here for months and I’m still alive”, chuckles Chohei Sato, chief of the village council, as he rolls down the window and inhales cheerfully. He pulls off the road, gets out of the car and buries the dosimeter in the grass. The reading doubles again.
>
> Iitate is located 45km (28 miles) from the Fukushima Dai-ichi nuclear power plant hit by a tsunami on March 11th this year. In the mountains above the town, the forests are turning the colour of autumn. But their beauty is deceptive. Every time a gust of wind blows, Mr Sato says it shakes invisible particles of radioactive caesium off the trees and showers them over the village. Radiation levels in the hills are so high that villagers dare not go near them. Mr Sato cannot bury his father’s bones, which he keeps in an urn in his abandoned farmhouse, because of the dangers of going up the hill to the graveyard.
>
> Iitate had the misfortune to be caught by a wind that carried radioactive particles (including plutonium) much farther than anybody initially expected after the nuclear disaster. Almost all the 6,000 residents have been evacuated, albeit belatedly, because it took the government months to decide that some villages outside a 30km radius of the plant warranted special attention. Now it offers an extreme example of how difficult it will be to recover from the disaster.
>
> That is mainly because of the enormous spread of radiation. Recently the government said it needed to clear about 2,419 square kilometres of contaminated soil—an area larger than greater Tokyo—that received an annual radiation dose of at least five millisieverts, or over 0.5 microsieverts an hour. That covered an area far beyond the official 30km restriction zone (see map). Besides pressure- hosing urban areas, this would involve removing about 5cm of topsoil from local farms as well as all the dead leaves in caesium-laden forests.
>
> However, Iitate’s experience suggests the government may be underestimating the task. Villagers have removed 5cm of topsoil from one patch of land, but because radioactive particles continue to blow from the surrounding trees, the level of radiation remains high—about one microsievert an hour—even if lower than in nearby areas. Without cutting down the forests, Mr Sato reckons there will be a permanent risk of contamination. So far, nobody has any idea where any contaminated soil will be dumped.
>
> The second problem is children’s health. On September 30th the government lifted an evacuation advisory warning to communities within a 20-30km radius of the plant. The aim was partly to show that the authorities were steadily bringing the crippled reactors under control.
>
> But these areas are still riddled with radiation hot spots, including schools and public parks, which will need to be cleaned before public confidence is restored. Parents say they are particularly concerned about bringing their children back because the health effects of radiation on the young are so unclear. What is more, caesium particles tend to lurk in the grass, which means radiation is more of a risk at toddler height than for adults. In Iitate, Mihori Takahashi, a mother of two, “believes only half of what the doctors say” and says she never wants to bring her children back. That, in itself, may be a curse. “The revival of this town depends on the children returning,” says Mr Sato.
>
> And even if people return, Mr Sato worries how they will make a living. These are farming villages, but it will take years to remove the stigma attached to food grown in Fukushima, he reckons. He is furious with Tokyo Electric Power, operator of the plant, for failing to acknowledge the long-term impacts of the disaster. He says it is a way of scrimping on compensation payouts.

One way to help overcome these problems would be to persuade people to accept relaxed safety standards. A government panel is due to propose lifting the advisory dose limit above one millisievert per year. This week in Tokyo, Wade Allison, a physics professor at Oxford University, argued that Japan's dose limit could safely be raised to 100 millisieverts, based on current health statistics. Outside Mr Sato's house, however, a reading of the equivalent of 150 millisieverts a year left your correspondent strangely reluctant to inhale.' [177]

Asahi Shimbun reported:

'Estimated 13,000 square km eligible for decontamination.

The central government will be responsible for decontaminating about 13,000 square kilometers across eight prefecture, or about 3 percent of Japan's total landmass, under new standards for cleaning up radiation from the Fukushima No. 1 nuclear power plant, according to Asahi Shimbun estimates. The Environment Ministry on Oct. 10 endorsed a basic policy to make the government responsible for decontaminating all areas with radiation levels exceeding 1 millisievert per year. Based on an earlier annual threshold of 5 millisieverts, the ministry initially said about 1,800 square km of land in Fukushima Prefecture would be subject to decontamination. But under the new standard, the size of the area will grow sevenfold.'

'The costs for the cleanup could also grow. In late September, the Environment Ministry said that full decontamination in areas above 5 millisieverts per year and partial decontamination for areas between 1 and 5 millisieverts would involve removing about 29 million cubic meters of surface soil and fallen leaves in forests. It predicted the decontamination measures would cost the central government about 1.2 trillion yen ($15.6 billion). Following protests by local governments, however, the ministry decided that the central government would assume responsibility for decontaminating all areas above 1 millisievert per year. That basic policy plan was accepted by an expert panel on radioactive contamination on Oct. 10.' [178].

Reuters reported:

'In northern Japan, stored-up radioactive ash and dehydrated sludge from the sewage treatment process alone totaled 52,000 tones in mid-September, up 63 percent from levels at the end of July, data from the Transport Ministry showed. The volume is still growing by about 360 tones a day.' [179]

The Guardian reported:

'Fukushima plant could take 30 years to clean up.

While radiation emissions have dropped significantly since the 11 March earthquake and tsunami, workers continue to operate in highly dangerous conditions. Towns near Fukushima have responded cautiously to plans to build temporary storage sites for massive quantities of radioactive debris generated by the accident.

Almost eight months after the start of the crisis the government says the facilities will not be ready for at least another three years. In the meantime, towns will have to store the contaminated waste locally, despite health concerns.

To reach its target of halving radiation levels within two years the government will have to remove large quantities of soil. Scraping 4cm of topsoil from contaminated farmland in Fukushima prefecture would create more than 3m tonnes of waste, says the agriculture ministry, enough to fill 20 football stadiums. Once completed, the storage facilities would hold soil and other contaminated waste for up to 30 years, local reports said.

"We have been aiming to start cleaning up as soon as possible", Toshiaki Kusano, an official in Fukushima city, told Reuters. "To do so we need to talk about where to store the waste, but we

> have not been able to answer the question residents are asking: how long it was going to stay there?” Fukushima city, 35 miles from the nuclear plant, contained enough radioactive waste to fill 10 baseball stadiums, he said.’ [180]

The IAEA reported that:

> ‘The remediation programme covers about 500 km2 where radiation dose levels are above 20 mSv/a and about 1300 km2 where radiation dose levels are between 5 mSv/a and 20 mSv/a.’ [181]

Trees and firewood stored outside were also exposed to the release. If burnt, the ash may contain high levels of radioactivity. [182]

The Mainichi Shimbun reported:

> ‘Radioactive crushed stone used in around 60 Fukushima buildings.
>
> The number of houses and condominiums confirmed to have been built using radiation-contaminated crushed stone quarried near the crippled Fukushima Daiichi nuclear plant has reached around 60 in Fukushima Prefecture, government sources said Sunday. The sources said the total number of buildings could top 100 if more surveys are conducted on the crushed stone that was shipped from a quarry in Namie located near the plant.
>
> A total of 5,725 tons of crushed stone was shipped from the quarry between the start of the crisis triggered by the March 11 earthquake and tsunami, and the designation by the government of the town as an evacuation zone the following month. The crushed stone, after being processed into concrete, was used in the construction of infrastructure such as housing, roads and river dikes at nearly 1,000 locations in the prefecture after the March disaster, they said.’ [183]

The Asahi Shimbun reported:

> ‘Road map released for Fukushima decontamination'. 2012-01-27.
> The Environment Ministry released a road map on Jan. 26 for decontaminating areas around the Fukushima No. 1 nuclear power plant, hoping to provide encouragement for residents forced to flee the radioactive fallout from the accident.’
>
> ‘The Environment Ministry used a three-way zoning structure based on radiation levels to determine priority for decontaminating land plots other than forests--including residential land for about 60,000 households, farmland, commercial and industrial estates.’
>
> ‘The efforts will start in areas with annual doses of 10-20 millisieverts, where a sizable reduction can be expected and the reduction goal is 10 millisieverts or less. A stricter reduction target of 1 microsievert per hour (corresponding to 5 millisieverts per year) or less will apply to schools.
>
> Decontamination work, including soil removal, will begin in July and hopefully be finished by December 2012, according to the road map. That time frame may provide an indication of when the evacuation order will be lifted.
>
> Owners’ approval will be sought and decontamination efforts will start in June for areas with annual doses below 10 millisieverts. Under the road map, decontamination will be finished by March 2013 in areas between 5 and 10 millisieverts and by March 2014 in areas between 1 and 5 millisieverts. March 2014 is also the target date for completing decontamination in the “no-residence zones”, or areas with annual doses between 20 and 50 millisieverts. The target for dose reduction there is 20 millisieverts or less per year. But for the "no-return zones," where annual doses exceed 50 millisieverts, the road map provided no specific schedule for decontamination work, leaving room for abandonment of efforts as an option. Only pilot decontamination programs will be conducted in those zones.’ [184]

> Minimising the loss of developed land will require vast efforts at decontamination, but this will be impractical for undeveloped land and forests. Also some land will be required for storing the huge volumes of radioactive waste.

10 COSTS OF HUMAN, LAND AND WATER CONSEQUENCES AND DECONTAMINATION AFTER FUKUSHIMA

H. Satoh stated:

> 'The damage to the Japanese economy as a whole has also been incalculable. Nearly 7,000 businesses, many of them manufacturers of highly specialised materials, are inside the no-entry zone (a 20km radius around Fukushima Dai-ichi). While they cannot resume normal operations (and these also include factories destroyed by the earthquake and tsunami), Japan's industrial supply chain remains crippled. Export industries, agriculture and fishery were also heavily affected as many countries imposed bans on all imports from Japan for fear of radiation contamination. The number of tourists to Japan also dropped sharply in the first two months, even in Kyoto, which is more than 800km from Fukushima.' [185]

Reuters reported:

> 'Japan faces costly, unprecedented radiation cleanup.
>
> "The technology for decommissioning and cleaning up plants has been studied for a while, but we hardly have any experience in decontaminating materials that were released into the environment", said Tetsuo Iguchi, a Nagoya University professor. "Fukushima is mountainous and such large-scale and highly concentrated contamination has not taken place on earth before in an area like this. How things will go is unpredictable."
>
> The area in need of cleanup could be 1,000 to 4,000 square km, about 0.3 to 1 percent of Japan's total land area, and cost several trillion to more than 10 trillion yen ($130 billion), double what it took to build six nuclear reactors at Fukushima Daiichi plant, some experts say.
>
> The government has banned people from entering an area in a 20 km radius surrounding the crippled plant and some 80,000 people have evacuated. Residents are calling on Tokyo Electric Power Co, the plant operator, to clean up the area, but the firm is still struggling to bring the reactors under control.
>
> Another major headache is where to store the radioactive waste like dirt and water generated from cleanup work.' [186]

Asahi Shimbun reported that the Environment Ministry predicted the decontamination measures would cost the central government about 1.2 trillion yen ($ 15.6 billion). [187]

Reuters reported:

> 'Fukushima victims are desperate, angry, homeless.
> About 80,000 people were forced to leave their homes by the nuclear crisis'. "Can we actually go back home? And if not, can you guarantee our livelihoods?" ' 'A government panel overseeing the compensation scheme estimates claims are likely to reach 3.6 trillion yen ($46.5 billion) in the financial year to next March'. 'The company expects a total of 300,000 claims from businesses given that the impact of the radiation crisis has been so widespread.' [188]

The Guardian reported:

> 'The government has so far earmarked 220bn yen (£1.75bn) for decontamination work, with an additional 460bn yen requested for next year. But according to one estimate the operation could end up costing 1.5tn yen.' [189]

The Asahi Shimbun reported:

> 'Up to 1 million residents of municipalities within 50 kilometers of the stricken Fukushima No. 1 nuclear power plant will be eligible for nuclear accident compensation, a government committee decided on Dec. 5'. 'There are some locations outside the 50-km radius where radiation levels are high, raising the possibility of the number of recipients increasing further.' [190]

> For Fukushima, the household and business compensation may be Y 3.6 trillion and the decontamination cost up to Y 10 trillion or more for a total of up to Y 14 trillion ($ 180 billion) or more.
>
> These costs may or may not include the equipment for and testing of human health and any treatment required for this and future generations, the necessary research on soil-to-food transfer factors and of testing foods for radioactivity for 10 to 20 years and more and the food discarded. However, all these should be paid by TEPCO. Yet no recompense is possible for the human misery, injury and loss of life-span, including of future generations, or likely for the loss of homes and communities and the economic outputs of farming, fishing, and industry in the contaminated areas.

10.1 INSURANCE, SUBSIDIES AND ETHICS

Swiss Re wrote:

> 'The anticipated extent of loss from a nuclear accident was generally believed to justify a special liability regime. Such a regime would both ensure proper compensation for the public and foster the development of the nuclear power industry, which would otherwise be faced with an overwhelming burden. Accordingly, the operators' interests were secured by limiting their liability in time and amount, and the liability regime was introduced in the Paris Convention on Third Party Liability in the Field of Nuclear Energy [of 1960] and in the Vienna Convention on Liability for Nuclear Damage [of 1963].' [191]

The Paris and Vienna Conventions were prompted by the Price-Anderson Act of 1957 in the USA and followed by the Nuclear Installations Act of 1965 (plus later amendments) in the UK, saying that the risk would be carried by the State. Such 'Statutory Indemnities' are described by the UK Government as 'unquantifiable'. This means 'unlimited', so must be taken as 'infinite'. [192]

The German Renewable Energy Association published on 2011-05-11 a study commissioned from 'Versicherungsforen Leipzig GmbH' on the calculation of an adequate insurance premium for the operators of nuclear power plants. [193] This found that the mean insured sum payable for a nuclear disaster could be 6090 billion euros. If passed on to consumers and spread over 50 years, the additional cost of electricity in euros per kWh would be 8.71 for each individual nuclear plant or 0.51 for all 17 plants in Germany and if spread over ten years, 67.3 or 3.96. (At 1 euro = £ 0.88, these are 766, 45, 5922 and 348 p/kWh). The study concluded that 'in practical terms, nuclear disasters are not insurable'. It has been reported briefly in English. [194]

If shared by the 54 nuclear power plants in Japan and spread over 50 or 10 years, this hypothetical additional insurance cost would be 14 or 110 p/kWh. At £ 1 = 130 yen, it would then be 18 or 143 yen/kWh.

The German Government set up an Ethics Commission for a Safe Energy Supply. This found that:

> 'The withdrawal from nuclear energy is necessary and recommended to rule out future risks from nuclear in Germany. It is possible because there are less risky alternatives'. [195].

> For ethical reasons, nuclear power stations should only continue to operate until the power they produce can be replaced by lower-risk sources of power. The output of nuclear power stations that is already dispensable today, amounting to 8.5 gigawatts, should be taken from the grid permanently. The temporary shutdown of the seven oldest nuclear power stations and of the Krümmel nuclear power station demonstrates that the 8.5 gigawatts of power they supplied can be replaced by lower-risk sources of power. [196]

> The Ethics Commission has come to the conclusion that a safe energy supply can be achieved which provides more jobs in business and manual trade without compromising environmental protection, whilst also avoiding a power shortage and having to import nuclear energy. [197]

T. Kitamura wrote:

> 'This US$10,000 is not everything. It is only part of compensation in an advance payment. The compensation is first paid by the nuclear energy liability insurance. TEPCO has paid the insurance premium for that. The insurance covers up to US$1,200 million. Beyond that, TEPCO bears. Beyond the amount TEPCO can bear, the government bears, which means the public pays as tax. The total amount of compensation may reach or exceed US$100 billion, in view of the compensation needed for farmers and fishermen.' [198]

Japan Today reported:

> 'Gov't may buy land within 20-km radiation no-go zone.
> TOKYO — The Japanese government is considering buying the land within the 20-km exclusion zone around the crippled Fukushima Daichi nuclear power plant. Reconstruction Minister Tatsuo Hirano, who visited Fukushima Prefecture on Sunday, said that due to extremely high levels of radiation within the 20-km zone, it may be unsafe for residents to return to their homes for a long time.' 'Hirano told NHK that in order to support those displaced by the disaster, the administration will have to buy the land and compensate the residents as well as build permanent housing for evacuees. A government report projected that radiation accumulated over one year at 22 monitoring sites within roughly 20 kilometers of the nuclear plant would be at least five times higher than the international safety standard.' [199]

The Asahi Shimbun reported:

> 'Insurance Companies Reject Fukushima Nuke Plant.'
>
> 'In both frameworks, payment can cover up to 120 billion yen ($ 1.6 billion) per nuclear plant. Electric power companies, in principle, pay the remainder of the burden. For the Fukushima accident, the maximum limit is well short of the estimated trillions of yen needed to cover all the damage compensation claims.' [200]

The Kuwait News Agency reported:

‘Fukushima plant operator gets USD 7.2 billion from public fund.
TOKYO, Nov 15 (KUNA) -- Tokyo Electric Power Co. (TEPCO) said Tuesday it has received JPY 558.7 billion (USD 7.2 billion) from the Nuclear Damage Liability Facilitation Fund, a state-backed funding body, to pay compensation to those affected by its Fukushima Daiichi nuclear power plant disaster in March. Earlier this month, the government approved the JPY 891 billion (USD 11.6 billion) rescue plan involving public funds after cash-strapped TEPCO promised to cut more than JPY 2.55 trillion (USD 33.1 billion) in costs over 10 years through measures such as reducing some 7,400 employees and cutting corporate pension payments for retirees under a business restructuring plan drawn up by TEPCO and the Nuclear Damage Liability Facilitation Fund. The funding injection allows the operator of the crippled Fukushima plant to pay compensation without going bankrupt, as the compensation to be paid by TEPCO could cost at least JPY 4.5 trillion (USD 58.3 billion) by 2013, according to a government estimate.’ [201]

The Asahi Shimbun reported:

'TEPCO to deposit 120 billion yen for future claims

Rejected by insurers, Tokyo Electric Power Co. plans to deposit 120 billion yen ($1.56 billion) in compensation reserves with a government body in case further accidents hit the Fukushima No. 1 nuclear power plant. It will be the first time a power company has made such a move against a possible nuclear accident. The crippled Fukushima plant will also be the first in Japan not covered by liability insurance. TEPCO’s board of directors was expected to approve the plan as early as Jan. 11. The company will deposit the money with the Tokyo Legal Affairs Bureau this week to cover compensation claims for possible future accidents at the plant. If the reactors at the plant are decommissioned without further incident, the money will be returned to TEPCO'.

'Power companies usually take out liability insurance worth 120 billion yen per nuclear plant with a private insurance company under the nuclear accident compensation law. But the Japan Atomic Energy Insurance Pool, an institution jointly formed by 23 nonlife insurers, decided last fall not to renew its insurance contract with TEPCO for the Fukushima No. 1 plant, given the risks involved in dealing with the unprecedented disaster in Japan. The contract expires on Jan. 15'. [202]

With insurance cover of only $ 1.6 billion the shortfall may be up to $ 178 billion or more, which will have to be met by the taxpayers. In the UK, the nuclear accident risk is carried by the State, under the Nuclear Installations Act of 1965. Such 'Statutory Indemnities' are described as 'unquantifiable', which means 'unlimited' or 'infinite'.

The Versicherungsforen Leipzig found that the hypothetical mean insured sum payable for a nuclear disaster in Germany could be 6090 billion (6 trillion) euros. (See Section 12 below). At 1 euro = £ 0.88, if shared by the 54 nuclear power plants in Japan and spread over 50 or 10 years, the value would be about 14 or 110 p/kWh. Then at £ 1 = 130 yen, it would be 18 or 143 yen/kWh. This and other subsidies means that nuclear power can never be competitive.

The German Government set up an Ethics Commission for a Safe Energy Supply. This found that: 'The withdrawal from nuclear energy is necessary and recommended to rule out future risks from nuclear in Germany. It is possible because there are less risky alternatives'. 'The Ethics Commission has come to the conclusion that a safe energy supply can be achieved which provides more jobs in business and manual trade without compromising environmental protection, whilst also avoiding a power shortage and having to import nuclear energy'.

11 FUKUSHIMA COULD HAVE BEEN FAR WORSE

11.1 LARGER INVENTORY AND RELEASE FRACTION

M. M. R. Williams reported:

> 'The first serious such accident was that at the Windscale, air-cooled, graphite moderated reactor in 1957 which, due to a Wigner energy release, caught fire. This led to substantial amounts of radioactive material being deposited over England, Wales and Northern Europe. It is estimated that about l015 Bq of the iodine and about l014 Bq of the caesium must have escaped. Since the reactor was not enclosed by a containment building the question of the effectiveness of such a structure could not be assessed; although there is no doubt that the filters in the stack proved very useful.' [203]

Chino et al reported:

> 'According to Eq. (2), [at Fukushima] the total amounts of 131 I and 137 Cs discharged into the atmosphere from 10 JST on March 12 to 0 JST on April 6 are estimated to be approximately 1.5 1017 and 1.3 1016 Bq, respectively.' [204]

R. Michel wrote that the "maximum physically possible" release would be the whole inventory of the damaged nuclear power plants. For Fukushima Reactors 1, 2, and 3 and Spent Fuel Pool 4, the inventory was estimated as I-131: 5E18, Cs-134: 2E18, and Cs-137: 2E18 Bq. [205]

The Guardian reported that:

> 'UK government's Fukushima crisis plan based on bigger leak than Chernobyl.'
>
> 'The British government made contingency plans at the height of the Fukushima nuclear crisis which anticipated a "reasonable worst case scenario" of the plant releasing more radiation than Chernobyl, new documents released to the Guardian show.'
>
> 'The UK government's response to the unfolding crisis is revealed in documents prepared for Sir John Beddington, the chief scientist and chair of the Scientific Advisory Group for Emergencies (Sage), and released to the Guardian under the Freedom of Information Act. The 30 documents include advice from the National Nuclear Laboratory on damage to the plant, public safety assessments from the Health Protection Agency (HPA), computer models of the radioactive plume from Defra's Radioactive Incident Monitoring Network (Rimnet), and the worst case scenario that might unfold at the plant.'
>
> 'The Nuclear Installations Inspectorate estimated this 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. Under that scenario, wind currents carried the plume directly towards Tokyo at a speed of five metres per second. Had the event happened, it could have released the equivalent of 9.92 million terabecquerels of radiation from iodine-131 into the open air, nearly double the 5.2 million terabecquerels released by the fire at the Chernobyl nuclear reactor in Ukraine in 1986.' [206]

Pretzsch et al estimated the radioactive inventory of Fukushima Reactors 1 to 3 and Spent Fuel Pools 1 to 4 as I-131: 1.186E19, Cs-134: 3.8E18 and Cs-137: 2.988E18 Bq and the total activity as 2.6E21 Bq. [207]

Date Reported	Author	Event	I-131 Source Term - Bq
1990	Williams, M.M.R.	Windscale	1E15
2011-05-02	Chino et al.	Fukushima	1.5E17
2011-05-16	Michel, R.	Fukushima 'maximum physically possible'	5E18
2011-06-20	NII	Fukushima	1.5E18
2011-06-20	NII	Chernobyl	5.2E18
2011-06-20	NII	Fukushima 'reasonable worst case scenario'	9.92E18

Table 10: Comparison of Estimated I-131 Source Terms for Various Radioactive Releases.

Michel estimated the Fukushima fuel inventory – and hence the maximum physically possible release - as I-131 of 5E18 Bq. However, Pretzsch et al later estimated the inventory of I-131 as about 1.2E19 Bq, so the NII Fukushima 'reasonable worst case scenario' release of about 1E19 Bq is consistent.

> The Fukushima release source term is far less than the maximum possible from Reactors 1 to 4. Compared with the Chino et al Fukushima I-131 release estimate of 1.5E17 Bq, the I-131 source term for the NII 'reasonable worst case scenario' is about 1E19 Bq, which is about 66 times higher. This is consistent with estimates of the radioactive inventories of I-131. It is roughly 100 times higher than INES 7 – the highest value defined by the IAEA – but it would be INES 9. The total for all nuclides would be larger. (See Sections 5.1 and 5.2 above). Therefore the total release source terms could be far larger than anything that has occurred to date. Also, multiple reactors and spent fuel pools per site and nearby sites would further increase the potential total release.

11.2 MORE OF THE RELEASE FALLING ON LAND AND MAJOR CITIES

Stohl et al reported that for Cs-137, the deposition (total emission) was about 35.8 PBq (3.58E16 Bq), (~ 42% of that estimated for Chernobyl), of which Japan 6.4 Pbq – 19%, Other land 0.7 Pbq – 2%, so total over land – 21%. (i.e. 7.1E15 Bq). In Fig. 16, the rightmost map shows the simulated surface concentration of 137Cs total from 00:00 UTC on 20 March to 12:00 UTC on 22 March.

> 'Luckily, it did not rain (also confirmed by radar data) exactly at the time when – according to our simulation – the highest concentrations were advected over Tokyo and other major Japanese cities. In such a disastrous scenario, much higher 137Cs deposition in the major population centers would have been possible.' [208]

Broomfiel reported:

> 'The model also shows that the accident could easily have had a much more devastating impact on the people of Tokyo. In the first days after the accident the wind was blowing out to sea, but on the afternoon of 14 March it turned back towards shore, bringing clouds of radioactive caesium-137 over a huge swathe of the country (see *Radioisotope reconstruction*). Where precipitation fell, along the country's central mountain ranges and to the northwest of the plant, higher levels of radioactivity were later recorded in the soil; thankfully, the capital and other densely populated areas had dry weather. "There was a period when quite a high concentration went over Tokyo, but it didn't rain," says Stohl. "It could have been much worse." ' [209]

> If the release had fallen on land and especially a major city such as Tokyo (population about 35 million), complete evacuation would be impossible and the health and economic consequences would have been much worse.

11.3 COMBINATION OF FAR LARGER RELEASE AND FALLING ON MAJOR CITIES

The Asahi Shimbun reported:

> ‘Government envisioned Tokyo evacuation in worst-case scenario.
>
> In a worst-case scenario, the central government would have requested the evacuation of Tokyo and everyone within a 250-kilometer radius of the damaged Fukushima No. 1 nuclear power plant. Goshi Hosono, minister in charge of the nuclear disaster, on Jan. 6 unveiled the emergency plan, which was personally drawn up two weeks after the Great East Japan Earthquake by Shunsuke Kondo, chairman of the Japan Atomic Energy Commission. The plan would have ordered mandatory evacuations of everyone within a 170-km radius of the plant. Evacuations would have been voluntary for those living between 170 km and 250 km from the plant, including the Japanese capital.’
>
> ‘The worst-case scenario imagined the melting of 1,535 fuel assemblies, an equivalent of fuel used for two reactors, kept in a spent fuel storage pool at the No. 4 reactor.’
>
> ‘The scenario envisioned that if another hydrogen explosion took place at the No. 1 reactor, workers would be forced to flee and suspend recovery operations, resulting in an enormous amount of radioactive material released from the pool in two weeks. The report also predicted the extent of soil contamination of areas required to evacuate in light of standards set after the 1986 Chernobyl accident in Ukraine. The scenario said areas within a 170-km radius of the plant would have been contaminated with 1,480 kilobecquerels per square meter, a level that requires mandatory evacuation.
>
> Areas where the government would have requested voluntary evacuations were predicted to have 555 kilobecquerels per square meter, extending to a 250-km radius, which included Tokyo and surrounding areas. If the release of cesium was limited to an equivalent of one reactor, the mandatory evacuation zone would have been a radius of 110 km and recommended evacuation a radius of 200 km. The report said it would have taken several decades for radiation levels to decrease naturally in the mandatory and voluntary evacuation zones. The report also said high radiation levels could have extended beyond the 250-km radius, and people in those areas would have also been advised to relocate.’ [210]

The Kondo report worst case data imply that the Evacuation Distance varies with (Ground Deposition)$^{-0.3932}$. At the ICRP dose criterion of 1 mSv/y, the Cs-137 ground deposition would be 3E4 Bq/m2, according to the IRSN. (See Section 6.2 above). So by extrapolation, the Evacuation Distance would be about 800 km.

The Courier-Mail reported:

> ‘Japan “had Tokyo evacuation plan”.
>
> Japan feared that tens of millions would be evacuated in a secret worst-case scenario report after Fukushima.
>
> The Japanese government's worst-case scenario at the height of the nuclear crisis last year warned that tens of millions of people, including Tokyo residents, might need to leave their homes, according to a report obtained by The Associated Press. But fearing widespread panic, officials kept the report secret.
>
> The recent emergence of the 15-page internal document may add to complaints in Japan that the government withheld too much information about the world's worst nuclear accident since Chernobyl. It also casts doubt about whether the government was sufficiently prepared to cope with what could have been an evacuation of unprecedented scale.
>
> The report was submitted to then-Prime Minister Naoto Kan and his top advisers on March 25, two weeks after the earthquake and tsunami devastated the Fukushima Dai-ichi nuclear power plant, causing three reactors to melt down and generating hydrogen explosions that blew away protective structures. Workers ultimately were able to bring the reactors under control, but at the time, it was unclear whether emergency measures would succeed.
>
> Mr Kan commissioned the report, compiled by the Japan Atomic Energy Commission, to examine what options the government had if those efforts failed. Authorities evacuated 59,000 residents

within 20 kilometres of the Fukushima plant, and thousands more were evacuated from other towns later. The report said there was a chance far larger evacuations could be needed.'

'The report looked at several ways the crisis could escalate - explosions inside the reactors, complete meltdowns, and the structural failure of cooling pools used for spent nuclear fuel. It said that each contingency was possible at the time it was written, and could force all workers to flee the vicinity, meaning the situation at the plant would unfold on its own, unmitigated. Using matter-of-fact language, diagrams and charts, the report said that if meltdowns spiral out of control, radiation levels could soar. In that case, it said evacuation orders should be issued for residents within a 170-kilometre radius of the plant and "voluntary" evacuations should be offered for everyone living within 250 kilometres.

That area that would have included Tokyo and its suburbs, with a population of 35 million people, and other major cities such as Sendai, with a million people, and Fukushima city with 290,000 people.

The report further warned that contaminated areas might not be safe for "several decades".

"We cannot rule out further developments that may lead to an unpredictable situation at Fukushima Dai-ichi nuclear plant, where there has been an accident, and this report outlines a summary of that unpredictable situation", says the document, written by Shunsuke Kondo, head of the commission, which oversees nuclear policy.' [211] [212]

The Kondo Report worst case considered two complete reactor-loads of spent fuel from Fukushima Daiichi Unit 4, but Units 1 to 4 comprised five loads, and Units 5 and 6 at least two more. Moreover, Fukushima Daiini Units 1 to 4 comprised at least four reactor-loads, with more in spent fuel pools. All are within the 20 km evacuation zone, so the Kondo worst case release could easily require all the operators to leave or even incapacitate them. Even shut-down, if any more decay heat cooling systems failed, they could give rise to further meltdowns and releases. Also multiple reactors and spent fuel pools per site and other sites nearby would further increase the potential release source terms.

The human health consequences – both locally and worldwide – would depend on how much material fell on land, the population density and the scope for evacuation. For the Fukushima disaster, only about 18% of the fallout was over Japan. The fallout from Chernobyl was almost 100% over land, but the low local population density limited the consequences. However, for the US WASH-740, WASH-1250 and CRAC-2 studies and the German study for Biblis, 100% was over land, with much high population densities and hence far higher health consequences. [213]

Furthermore, Chernobyl showed that – with particular combinations of wind and rain – the radioactive release could travel more than 2400 km to the hills of the UK. The ground deposition was such that – even 25 years later – some Cumbrian and Welsh hill farms are still contaminated and subject to restrictions on sheep movement. [214]

The Kondo report worst case data imply that the Evacuation Distance varies with (Ground Deposition) $^{-0.3932}$. Relative to the NII Fukushima release, the NII 'reasonable worst case scenario' release is 66 times as large. So assuming that the Ground Deposition is proportional to the release, the Evacuation Distance would be $66^{0.3932}$ = 5.2 times as large.

The contaminated area could be between (Evacuation Distance) ^{1} and (Evacuation Distance) ^{2} – i.e. 5.2 to 27 times as large. So assuming that the population and property densities are constant, the compensation and decontamination cost for a worst case release could be between $ 936 billion and $ 4.8 trillion – i.e. roughly £ 1 trillion. This is of the same order as the hypothetical mean insured sum payable for a German nuclear disaster of 6 trillion euros estimated by the Versicherungsforen Leipzig. (See Section 10.1 above).

If a worst case release fell on a major city, complete evacuation would be impossible and the health effects would affect millions. The compensation and decontamination cost for a worst case release could be between $ 936 billion and $ 4.8 trillion – i.e. roughly £ 1 trillion. This is of the same order as the hypothetical mean insured sum payable for a German nuclear disaster of 6 trillion euros estimated by the Versicherungsforen Leipzig. So the consequences of a major radioactive release are comparable to those of nuclear weapons, but are self-inflicted. Moreover, the NII estimate of the 'reasonable worst case scenario' and the Kondo report on the worst case consequences are from within the UK and Japanese nuclear communities. So such horrific consequences are undeniable.

When the next major release occurs, the citizens will demand immediate shut-down of all nuclear power, as has happened in Japan. Yet they would still suffer huge health effects, a damaged country and vast amounts of radioactive waste. Germany, Switzerland and Italy have already decided to join many other countries and phase out nuclear power. Meanwhile Japan has shut down most of the nuclear power plants, and will shut down the rest this spring. Whether the citizens will allow any to be re-started remains to be seen.

In the light of the Kondo report on Fukushima, studies of the consequences for a worst case release must be carried out for each country where nuclear power plants are installed or proposed. Since fallout crosses national boundaries, the consequences should include those for neighbouring countries. Plume models can be used to estimate the ground and marine depositions for various combinations of wind and rain. Following the 'precautionary principle', the ECRR model must be used to estimate the human health effects. Moreover, these studies must be carried out independently of all nuclear power interests, including the IAEA and the national nuclear regulatory agencies.

12 CONSEQUENCES OF A MAJOR RADIOACTIVE RELEASE IN THE UK

Dr Clifford Beck of the US Atomic Energy Commission (AEC) said in 1959:

> ‘If worst conceivable accidents are considered no site except one removed from populated areas by hundreds of miles would offer sufficient protection.’ [215]

Following the nuclear accident at Three Mile Island in 1979, Sandia produced the 'CRAC-2' study on the siting criteria for nuclear power plants in 1982. Most were located near to major cities and for a major release, the 'Peak Early Fatalities' were estimated at up to 100,000. [216]

It was reported that:

> ‘Emergency planning for a nuclear accident in the UK is to be radically overhauled following a recent exercise at the Bradwell reactor in south-east England. The exercise tested the response to a large passenger aircraft crashing into the reactor. One of the significant finding was that radiation would spread to least 10 km within a few hours of an accident. Until now all emergency planning has been based on radiation affecting only within 3km of a reactor. In the Bradwell exercise an estimated 500,000 people would have needed evacuation.’ [217]

Hirschberg et al noted that:

> In particular, early fatalities can be extrapolated from one site another from the ratio of population within 8 to 10 km'. 'Delayed cancer deaths are found to be strongly correlated to the total population within 80 to 120 km'.'Cancer deaths occurring from ingestion (late deaths) ... are considered proportional to the ratio of populations within 800 km'. 'Finally, land contamination is assumed to be correlated to the ratio of land fractions to 120 km, even though the correlation was found to be weaker than the ones found for health effects'.

The map on page 82 shows the sites with circles of 100 and 800 km. These are the approximate extents of delayed cancer deaths and late deaths. [218]

The UK Weightman report includes:

> ‘Conclusion IR-7: There is no need to change the present siting strategies for new nuclear power stations in the UK.
>
> Recommendation FR-6: The nuclear industry with others should review available techniques for estimating radioactive source terms and undertake research to test the practicability of providing real-time information on the basic characteristics of radioactive releases to the environment to

the responsible off-site authorities, taking account of the range of conditions that may exist on and off the site.

Recommendation FR-7: The Government should review the adequacy of arrangements for environmental dose measurements and for predicting dispersion and public doses and environmental impacts, and to ensure that adequate up to date information is available to support decisions on emergency countermeasures.' [219]

However, it makes no mention of any such decision support assets being available in the UK. Yet the UK has had nuclear facilities and power plants capable of major radioactive releases for over 60 years.

The UK siting criteria for nuclear power plants are based on those originally developed for Magnox and AGR stations, adjusted for PWRs such as Sizewell B. They consider a radioactive release of 1000 Curies (3.7E13 Bq) of I-131 and a distance of 30 km. [220] [221] Yet at Fukushima, the release of I-131 was about 1.5E17 Bq, which is 4000 times as much and for the NII Fukushima 'reasonable worst case scenario', it is about 1E19 Bq, which is 270,000 times as much. (See Section 11.1 above). Also in the Kondo Report worst-case scenario, residents within a radius of 170 km of the power station, and possibly even further away, would be forced to evacuate. Those living within a radius of between 170 km and 250 km of the plant, including Tokyo, could chose to evacuate voluntarily. The report also said high radiation levels could have extended beyond the 250-km radius, and people in those areas would have also been advised to relocate. [222] By extrapolation, at the ICRP dose criterion of 1 mSv/y, the radius would be about 800 km. (See Section 11.3 above).

Fig. 4 is a map of Great Britain, showing the areas threatened by the ten proposed nuclear power plants and an example of fallout from Hinkley Point extending to 170 km. Evidence from Fukushima shows that fallout from Hinkley Point could require evacuation for 170 to 250 km or more. Carried by south-westerly winds, this would reach Birmingham, or on the prevailing westerlies, London and beyond. Likewise fallout from Sizewell, carried by north-easterly winds for 170 km, would reach London.

> Dr Clifford Beck of the US Atomic Energy Commission (AEC) said in 1959: 'If worst conceivable accidents are considered no site except one removed from populated areas by hundreds of miles would offer sufficient protection'.
>
> Following the nuclear accident at Three Mile Island in 1979, Sandia produced the 'CRAC-2' study on the siting criteria for nuclear power plants in 1982. Most were located near to major cities and for a major release, the 'Peak Early Fatalities' were estimated at up to 100,000.
>
> The UK Government has proposed ten sites for new nuclear power plants, of which three are very close together. [223] Also, it is proposed to install more than one unit per site, each far larger than Fukushima in output and hence nuclear fuel inventory. Just who and how many would suffer death, injury, exclusion and economic loss would depend on which site produced the release, its magnitude, the direction of the wind, and whether it was raining or snowing as the plume passed. The ground level concentration pattern of radioactive fallout - for a constant wind over a level surface - is approximately elliptical. [224] For the Kondo Report worst case release, with evacuation compulsory to 170 km and voluntary to 250 km or more, this could be from Hinkley Point to Birmingham or London. By extrapolation, at the ICRP dose criterion of 1 mSv/y, the radius would be about 800 km. (See Section 11.3 above).
>
> Fig. 4 is a map of Great Britain, showing the areas threatened by the ten proposed nuclear power plants and an example of fallout from Hinkley Point extending 250km to London. Evidence from Fukushima shows that fallout from Hinkley Point could require evacuation for 170 to 250 km or more. Carried by south-westerly winds, this would reach Birmingham, or on the prevailing westerlies, London and beyond. Likewise fallout from Sizewell, carried by north-easterly winds for 170 km, would reach London. After Fukushima, such consequences would be inexcusable, especially as the UK suffered from Windscale and Chernobyl. So the UK siting criteria are wholly inadequate and almost all the citizens of Britain are threatened by the existing and proposed nuclear power plants. In the words of Dr John Gofman, this is 'licensing random premeditated murder'. Thus the existing nuclear power plants must be phased out forthwith and the proposed ones abandoned.

13 CONCLUSIONS

This study is based on evidence on the Fukushima disaster and it's consequences, almost all from the internet. Many quantitative studies have been found, but no proper studies from the IAEA or the UK ONR. The fast-moving and highly dangerous events of such a disaster require decision support. Thermal models of the reactors and spent fuel pools are essential to predict their behaviour under Station Blackout and evaluate possible counter-measures. Also plume (dispersion) models of possible radioactive releases are essential to inform decisions on the magnitude and direction of evacuations. The Japanese have such a plume model, but it was ignored until later. Also they had no instrument for airborne radioactivity measurements at hand and had to rely initially on aerial surveys carried out by the Japan-based US Emergency Response Centers. These deficiencies were omitted or downplayed in the reports of the IAEA Fact Finding Mission, but most were included in the report of the Hatamura Panel.

Following the disaster, nearly 15,000 workers have received doses of up to 250 mSv. Several have received more and at least one has died due to internal radiation. Excess cancers and resulting deaths may take up to 50 years to appear. Using widely accepted dose-effect models, the excess cancer deaths are estimated as 350 to 3000, while with other dose-effect models they may be 100,000 to 200,000, though all these should be reduced by evacuation.

About 80,000 persons have been forced to evacuate parts of Fukushima prefecture and live elsewhere. Radioactivity above Japanese government limits has been found in many foods, including rice, beef and fish. This would cause internal exposure if eaten, and has destroyed the businesses of farmers and fisherfolk over wide areas. The compensation for persons and businesses has been estimated at 3.6 trillion yen ($ 47 billion).

The area of land contaminated with radioactive cesium to more than 10,000 Bq/m2 is about 30,000 km2, some 8% of the land area 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 dose to humans would be over 1 mSv/y is about 13,000 km2. It would require removing about 29 million cubic meters of topsoil and fallen leaves, and such radioactive waste needs land for storage. The cost of the decontamination measures have 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. In principle, the electric power companies should pay the rest, but TEPCO is virtually bankrupt. So almost all the cost must be met by the taxpayers. This and other subsidies means that nuclear power can never be competitive.

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 higher by up to 5 times. The radioactive plume passed over Tokyo, but by chance it was not raining. If it had been, the human health and other consequences would have been hugely higher. Scenarios with larger releases, all over land and over crowded cities, have consequences that are even more horrific.

Germany, Switzerland and Italy have decided to join many other countries and phase out nuclear power. Also Japan has shut down almost all the nuclear power plants, and will shut down the rest this spring. Whether the citizens will allow any to be re-started remains to be seen. Economy minister Yukio Edano said he does not expect any nuclear power plant to be operating this summer, but thermal power and conservation efforts should be enough for the nation to get by.

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 NII Fukushima 'reasonable worst-case scenario' release is about 270,000 times as much. According to the Kondo Report, the worst case release would require evacuation for 170 or 250 km or more, e.g. from Hinkley Point to Birmingham or London. Also the compensation for the land and property losses and the decontamination costs would be far larger than for Fukushima, at roughly £ 1 trillion. So the UK siting criteria are wholly inadequate and almost all the citizens of Britain are threatened by the existing and proposed nuclear power plants. In the words of Dr John Gofman, this is 'licensing random premeditated murder'. Thus the former must be phased out forthwith and the latter abandoned.

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This work was funded by the author.

14 GLOSSARY

1/2T – The half-life of a nuclide. That is, the time for the radioactivity to fall by one-half.

Actinide – a radioactive element with an atomic number from 89 (actinium) to 103 (lawrencium).

AEC - (US) Atomic Energy Commission. Superceded by US DOE and US NRC.

Aerosol - 'a suspension of fine particles in the atmosphere which can arise due to a core melt, leading to vaporized fission products or as the result of a fire'. [225]

Bq – Bequerel – SI unit of radioactivity.

BEIR VII - Beir VII: Health Risks from Exposure to Low Levels of Ionizing Radiation. [226]

BWR – Boiling Water Reactor (as Fukushima Daiichi Reactors 1-6).

CDF – Core Damage Frequency.

Ci – Curie – old unit of radioactivity.

CNSC – Canadian Nuclear Safety Commission.

CTBTO – Comprehensive Test Ban Treaty Organization. It operates a worldwide network of radioactivity monitoring stations.

Curie – 3.7E10 Bequerels.

Decay Heat – heat produced by a nuclear reactor even after it has been shut-down.

DNA – Deoxyribonucleic acid, the genetic material of all living things.

DOE – US Department of Energy.

ECRR – European Committee on Radiation Risk. [227]

GRS – German Nuclear Safety Organization.

Gy – Gray – SI unit of absorbed dose.

Half-life - the time for the radioactivity of a nuclide to fall by one-half.

HRA – Human Reliability Analysis.

IAEA – International Atomic Energy Agency.

ICRP – International Commission on Radiation Protection. [228] [229]

IKE - Institute for Nuclear Technology and Energy Systems, University of Stuttgart, Germany.

INES – International Nuclear Event Scale (0-7). [230]

IPPNW - International Physicians for the Prevention of Nuclear War

IRSN – French Nuclear Safety Institute.

JAEA – Japan Atomic Energy Authority.

JAIF – Japan Atomic Industry Forum.

JRC – Joint Research Centre of the European Union.

JST – Japanese Standard Time (UTC + 9:00)

KI – Potassium Iodide (tablets). Sometimes provided as a mitigation measure after a nuclear release.

LOCA – Loss of Cooling Accident.

MAAP – a thermal model of a nuclear reactor and/or spent fuel pool.

METI – Japan Ministry of Economy, Trade and Industry.

MEXT – Japan Ministry of Education, Culture, Sports, Science and Technology (or Science Ministry, for short).

Model – mathematical model, embodied in a software package, used for simulation runs/estimates.

MWth – MegaWatt (1E6 Watts) thermal.

NHK – Japanese Broadcasting Corporation, originator of the NHK World television channel.

NII – UK Nuclear Installations Inspectorate, now the Office of Nuclear Regulation.

NISA – National Industrial Safety Agency of Japan.

NISC – National Information Security Center of Japan.

NPP – Nuclear Power Plant.

NRC – US Nuclear Regulatory Commission.

NSC – Nuclear Safety Commission of Japan.

Nuclide – an atom of specific properties, such as the number of neutrons and protons and the energy state of its nucleus.

ONR – UK Office of Nuclear Regulation.

PSA - Probabilistic Safety Analysis.

PWR – Pressurized Water Reactor.

RPV – Reactor Pressure Vessel, the second containment after the cladding of the nuclear fuel.

SBO – Station Blackout (loss of power from the grid and the backup diesel generators).

SI – Systeme International, the world-standard rational system of units.

SPEEDI – a plume (dispersion) model for airborne releases, here of radioactive materials.

Sv – Sievert – SI unit of (human) dose equivalent.

TEPCO – Tokyo Electric Power Company, owners and operators of the Fukushima Daiichi nuclear power plant.

UNSCEAR – United Nations Scientific Committee on the Effects of Atomic Radiation. [231]

US DOE – US Department of Energy.

WHO – World Health Organization.

ZAMG – Central Establishment for Meteorology and Geodynamics, Austria.

15 FIGURES

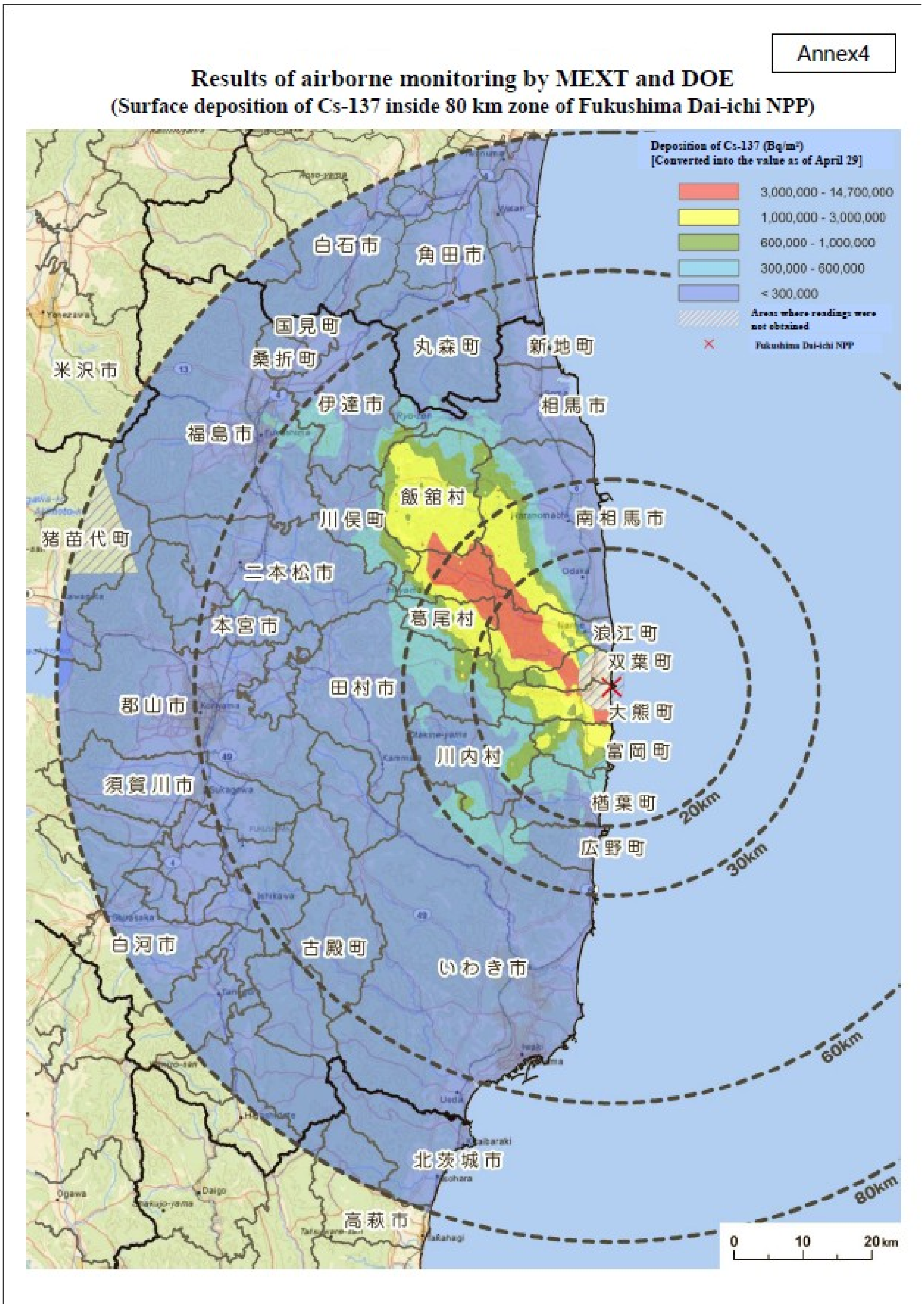

Fig. 1 – 80 km zone of Fukushima prefecture showing the deposition of Cs-137.

Restricted Area, Deliberate Evacuation Area, Evacuation-Prepared Area in case of Emergency And Regions including Specific Spots Recommended for Evacuation (As of August 3, 2011)

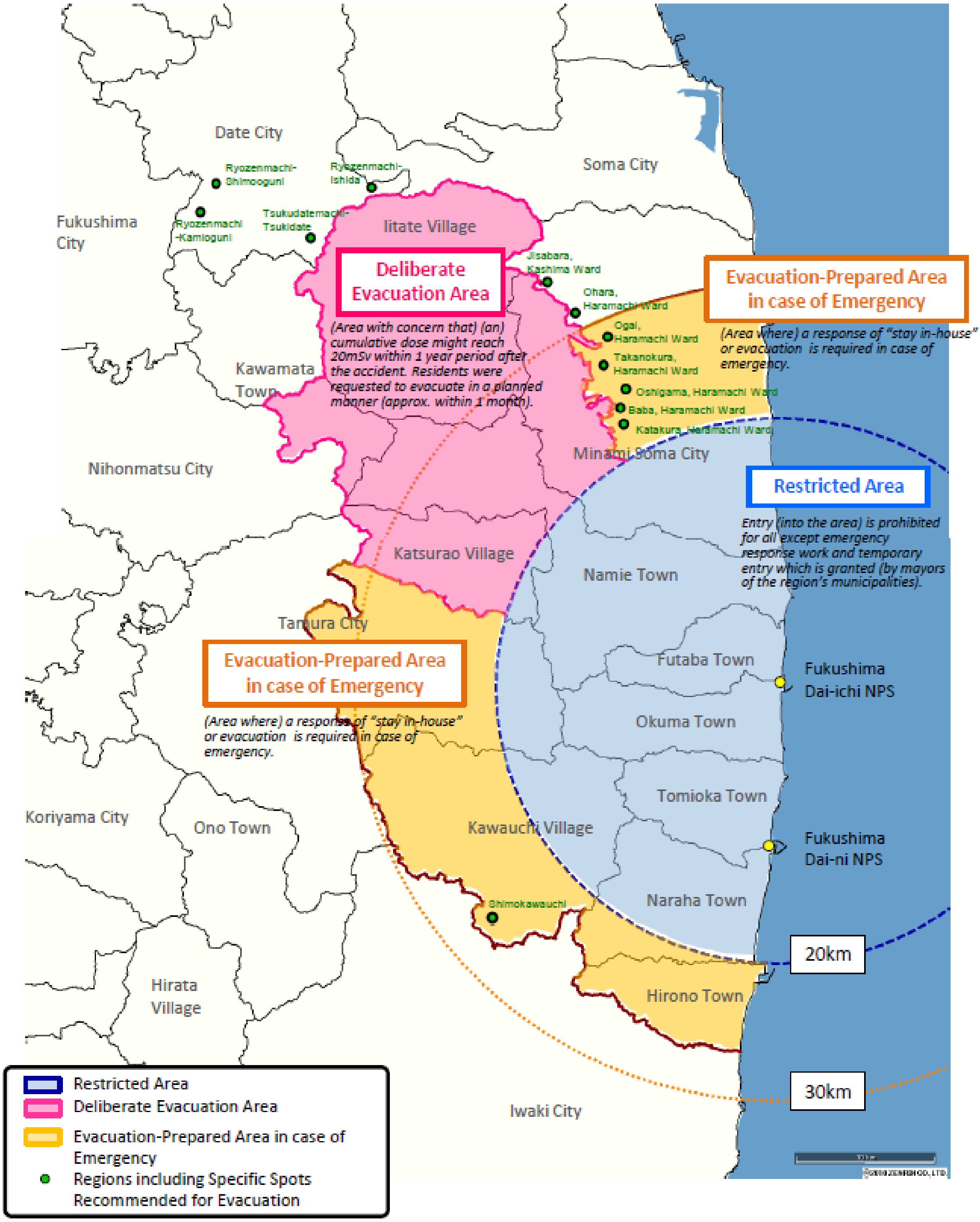

Fig. 2 - Restricted Ar'ea, Deliberate Evacuation Area, Evacuation-Prepared Area.

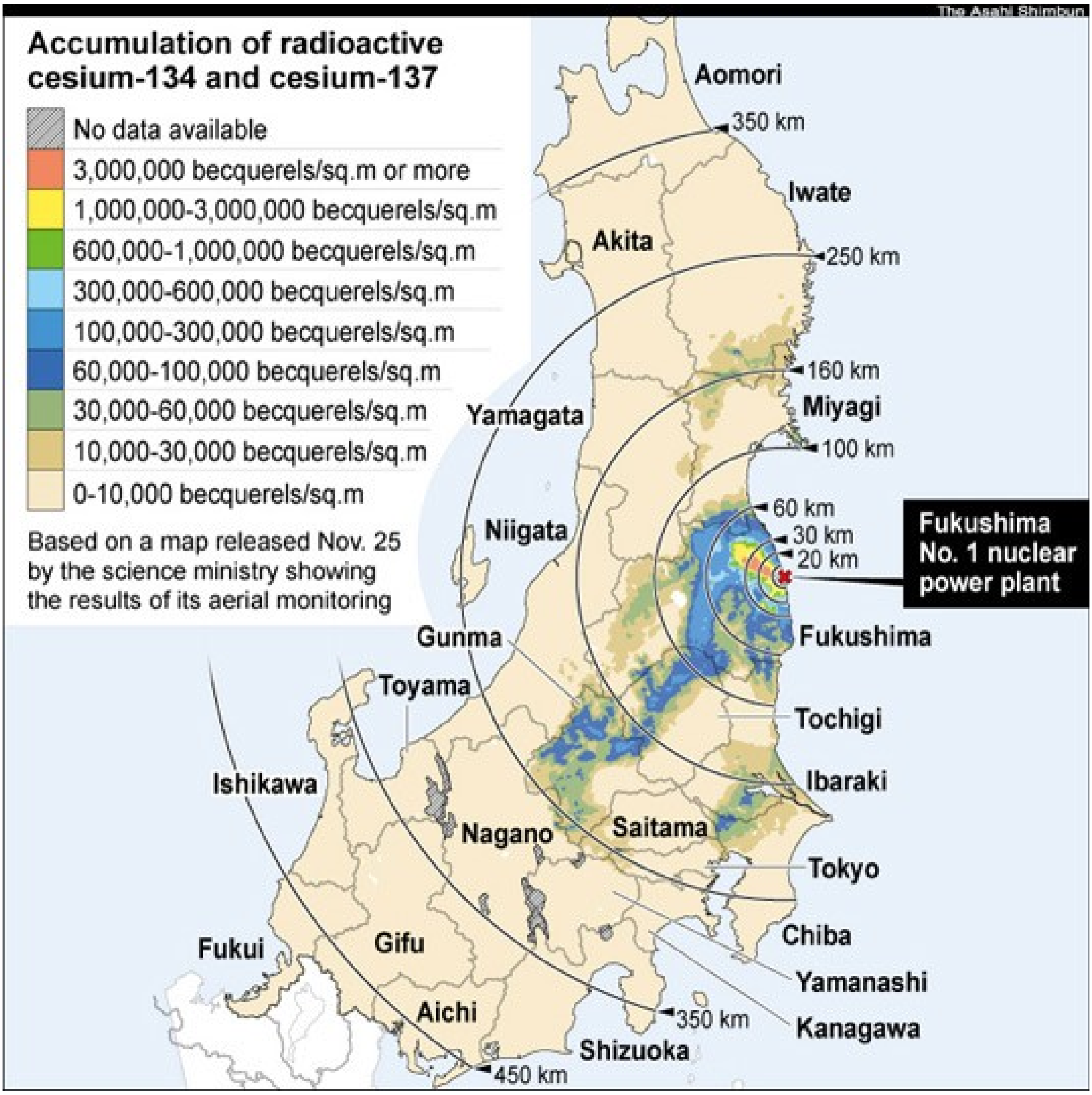

Fig. 3 - Tokyo and 21 other prefectures, showing the deposition of Cs-134 and Cs-137.

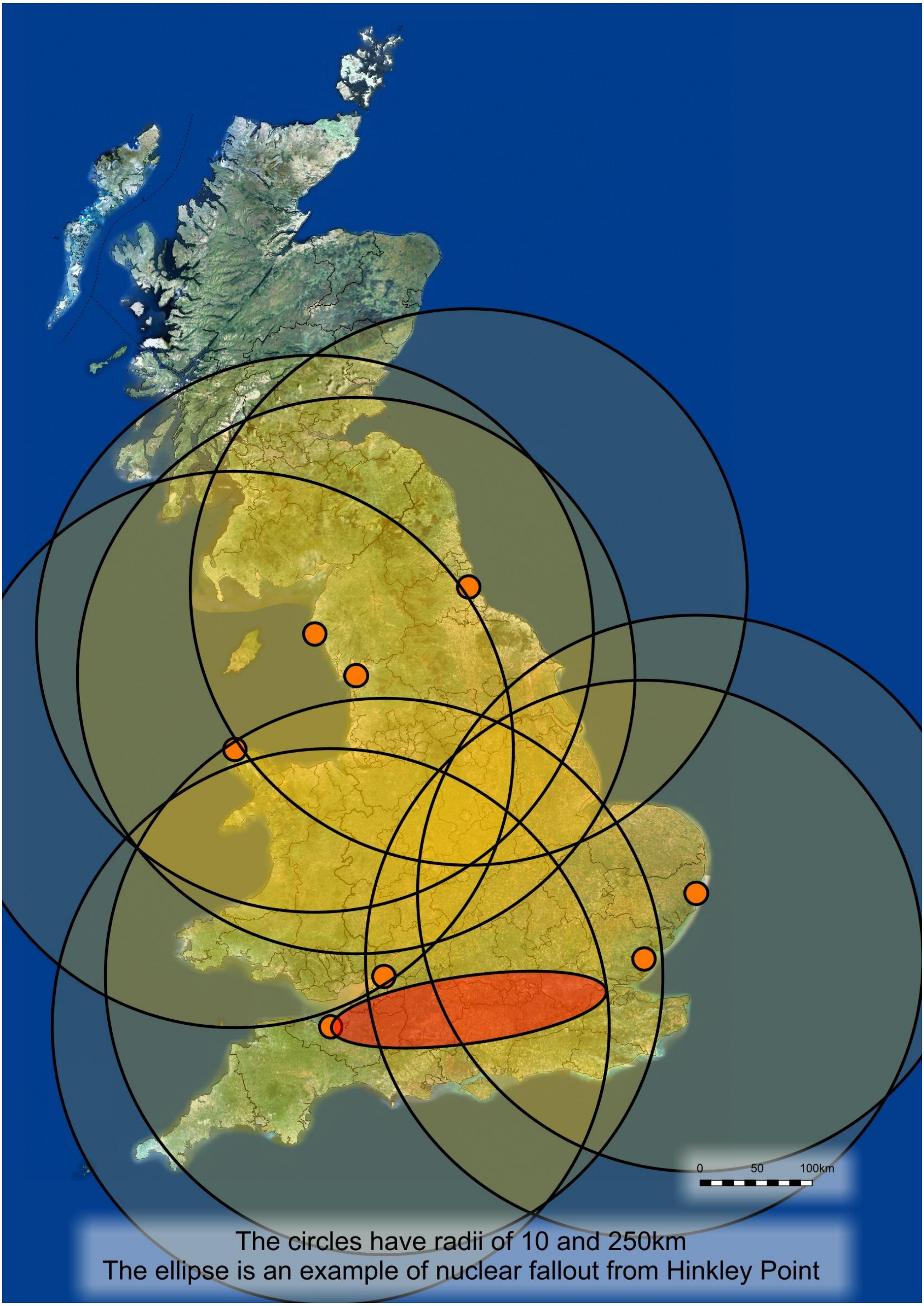

Fig. 4 - Areas Threatened by Proposed Nuclear Power Plants.

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