Fukushima at 10 - What Happened and the Real Lessons for Energy Policy

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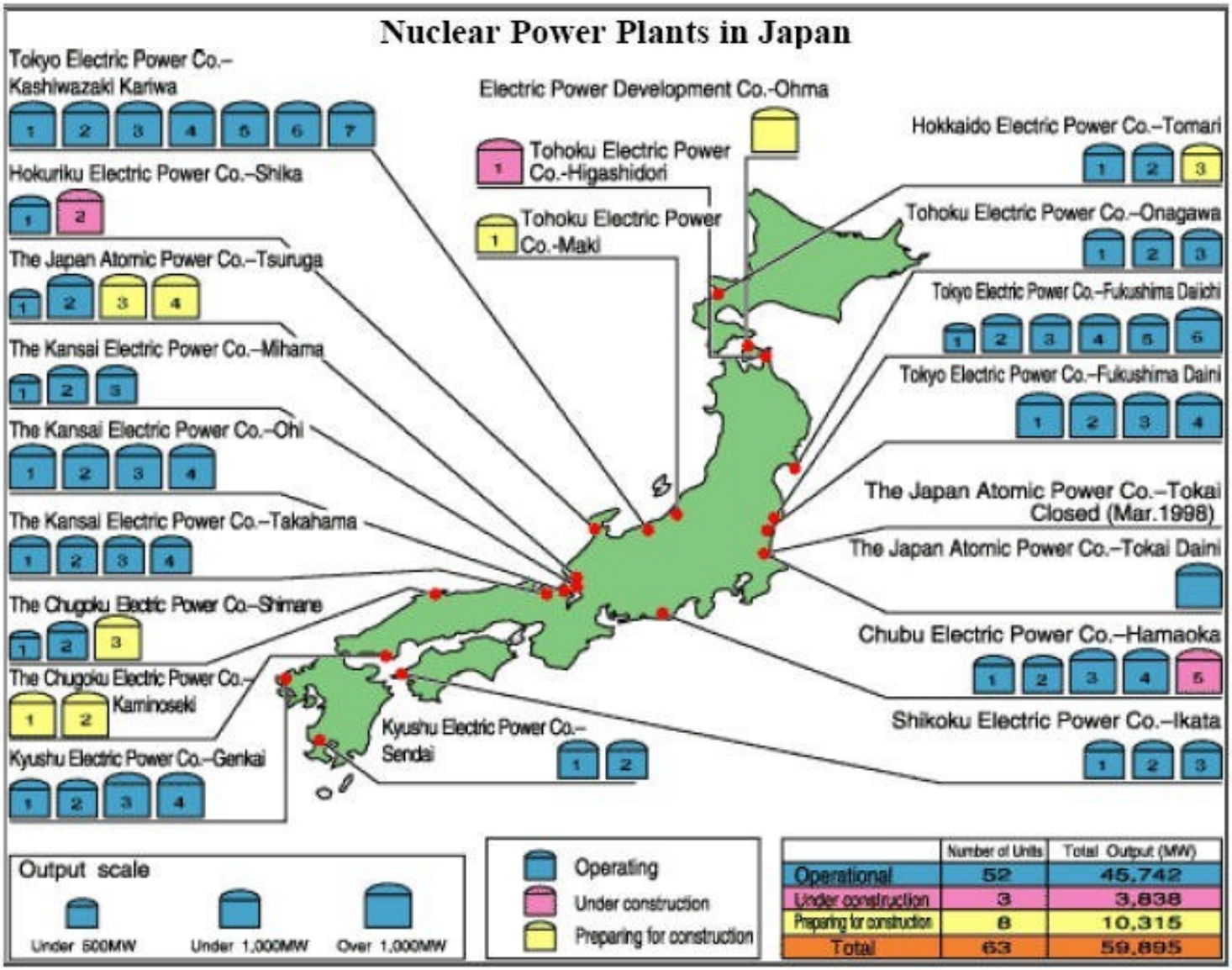
Before the Disaster

- The US persuaded Japan to install over 50 npps despite frequent earthquakes and tsunamis
- TEPCO retained the standard GE designs with standby diesel generators located low down
- TEPCO ignored 2000 and 2008 studies warning of tsunamis that could flood the plant.
  Yet the regulator NISA took no action
- TEPCO was found guilty in 2002 of falsifying inspection reports

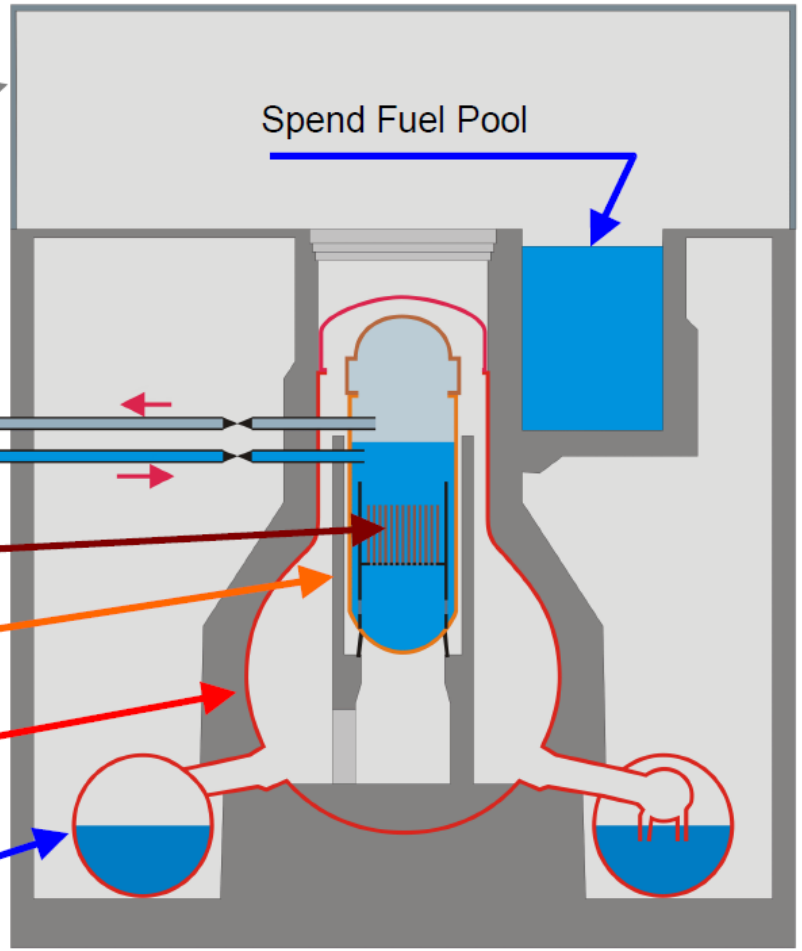


nucleartourist.com

The Fukushima Daiichi Incident

1. Plant Design

- Reactor Service Floor (Steel Construction)
- Concrete Reactor Building (secondary Containment)
- Reactor Core
- Reactor Pressure Vessel
- Containment (Dry well)
- Containment (Wet Well) / Condensation Chamber



AREVA

Decay Heat after Shut-down

Always occurs with all nuclear power plants.

In the event of a Station Black-Out (SBO),

can give rise to a Loss of Cooling Accident (LOCA)

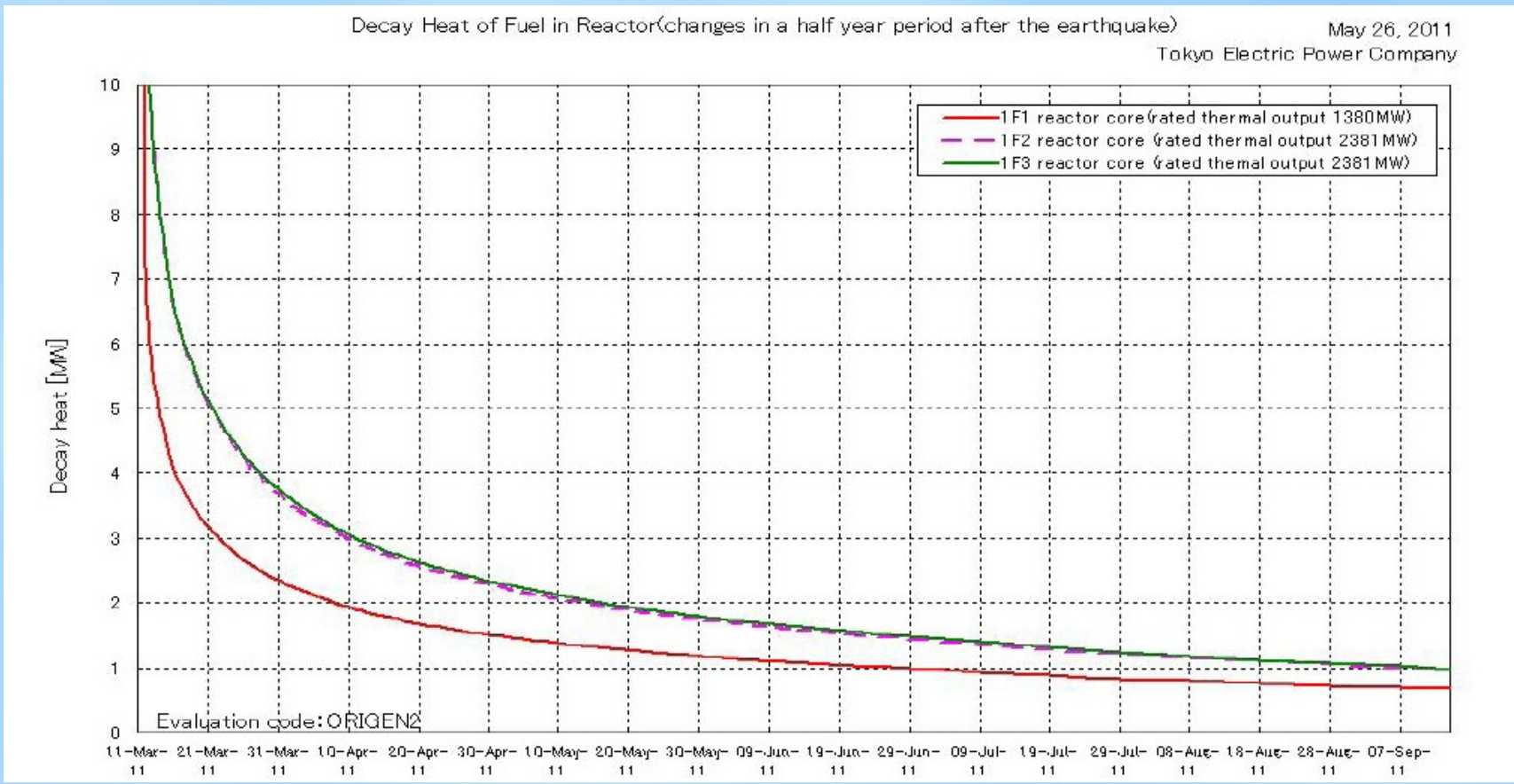
and within hours, Meltdown of nuclear fuel rods,

and the production of Hydrogen, which can explode,

breaching the final containment and,

releasing Radioactive Fission Products and Fallout

Decay Heat Curves - Fukushima



Loss of Cooling – Reactor 1

- Emergency cooling by Isolation Condenser (IC) which has water for 8 hours
  Needs no power, but off when batteries ended
- Could not determine status via instruments
- Steam from the ‘pig’s nose’ was misinterpreted as indicating that the IC was working.
  This was never tested in 40 years
- Hence Core Meltdown, Hydrogen Explosion and Radioactive Release

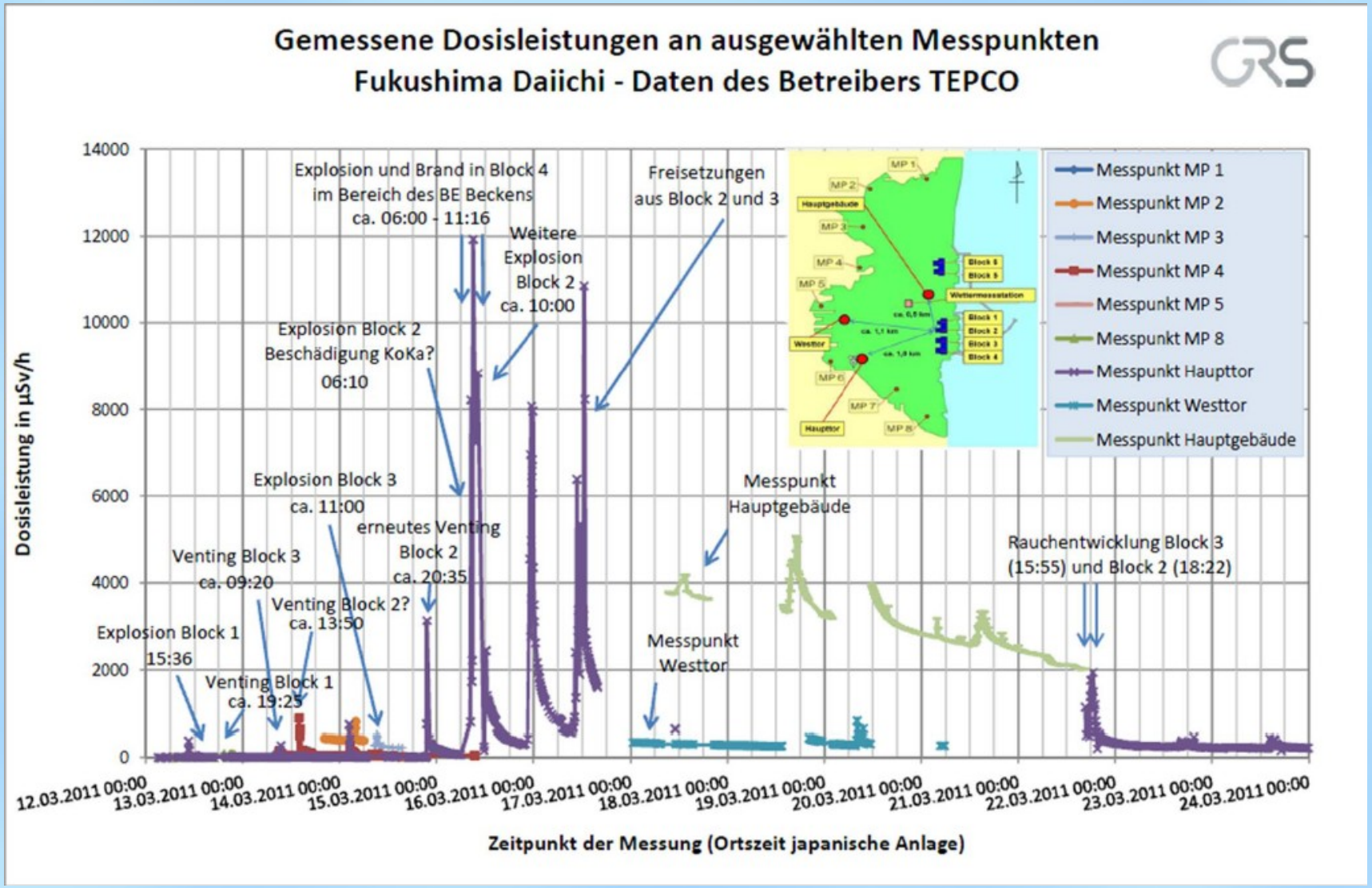
Loss of Cooling – Reactor 3

- Emergency Cooling by Reactor Core Isolation Cooling (RCIC), which needs a pumped water supply
- Safety Relief (SR) valve needed 120 vdc, so when the backup batteries ended, it could not be opened.
  They then tried using batteries from worker's cars
- But none of 8 would open when the primary containment pressure was high – 600 kPa - a fundamental design flaw
- They tried substitute water injection from fire engines.
  But leakage was 55% - another major design flaw.
  This was never tested in 40 years (also for R1 and R2)
- Hence Core Meltdown, Hydrogen Explosion and Radioactive Release

Loss of Cooling – Reactor 2

- Emergency Cooling by Reactor Core Isolation Cooling (RCIC), which needs a pumped water supply
- Safety Relief (SR) valve needed 120 vdc, so when the backup batteries ended, it could not be opened.
  They then tried using batteries from worker's cars
- But none of 8 would open when the primary containment pressure was high – 600 kPa - a fundamental design flaw
- Attempted 'vent' to lower pressure. Valve needed compressed air, but 70 m pipe was only seismic class C and failed - another major design flaw.
- Hence Core Meltdown and Radioactive Release

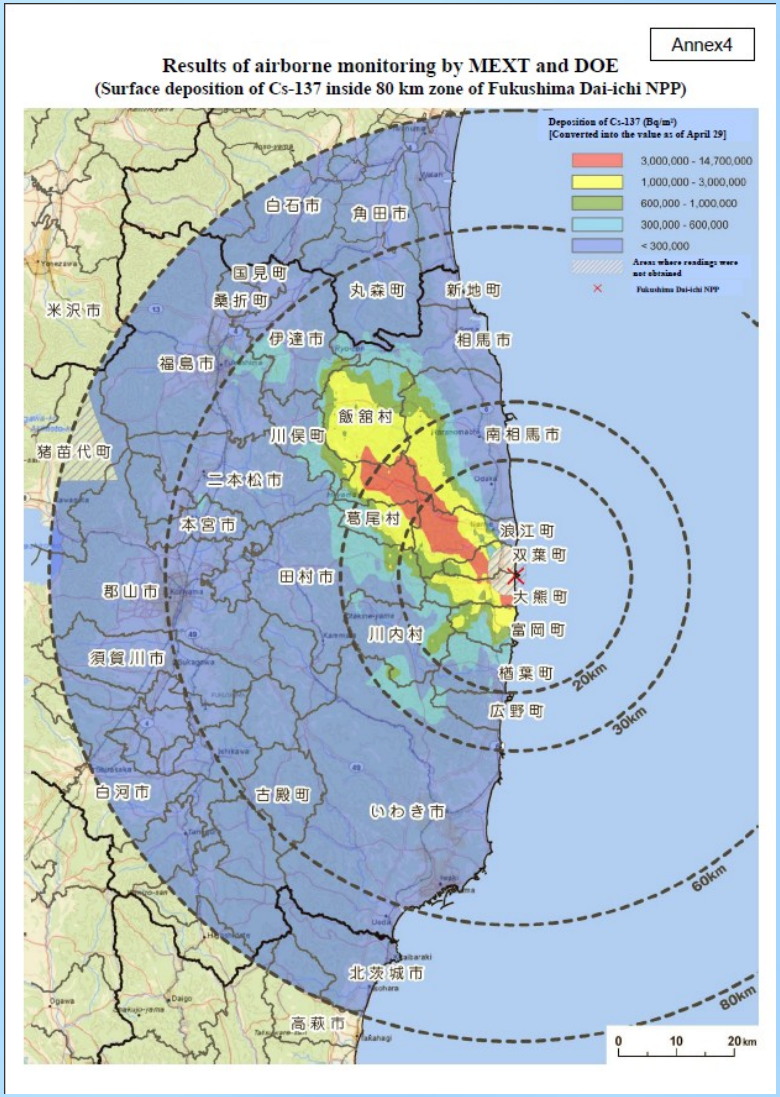
Fukushima Daiichi – Dose Rates v Time



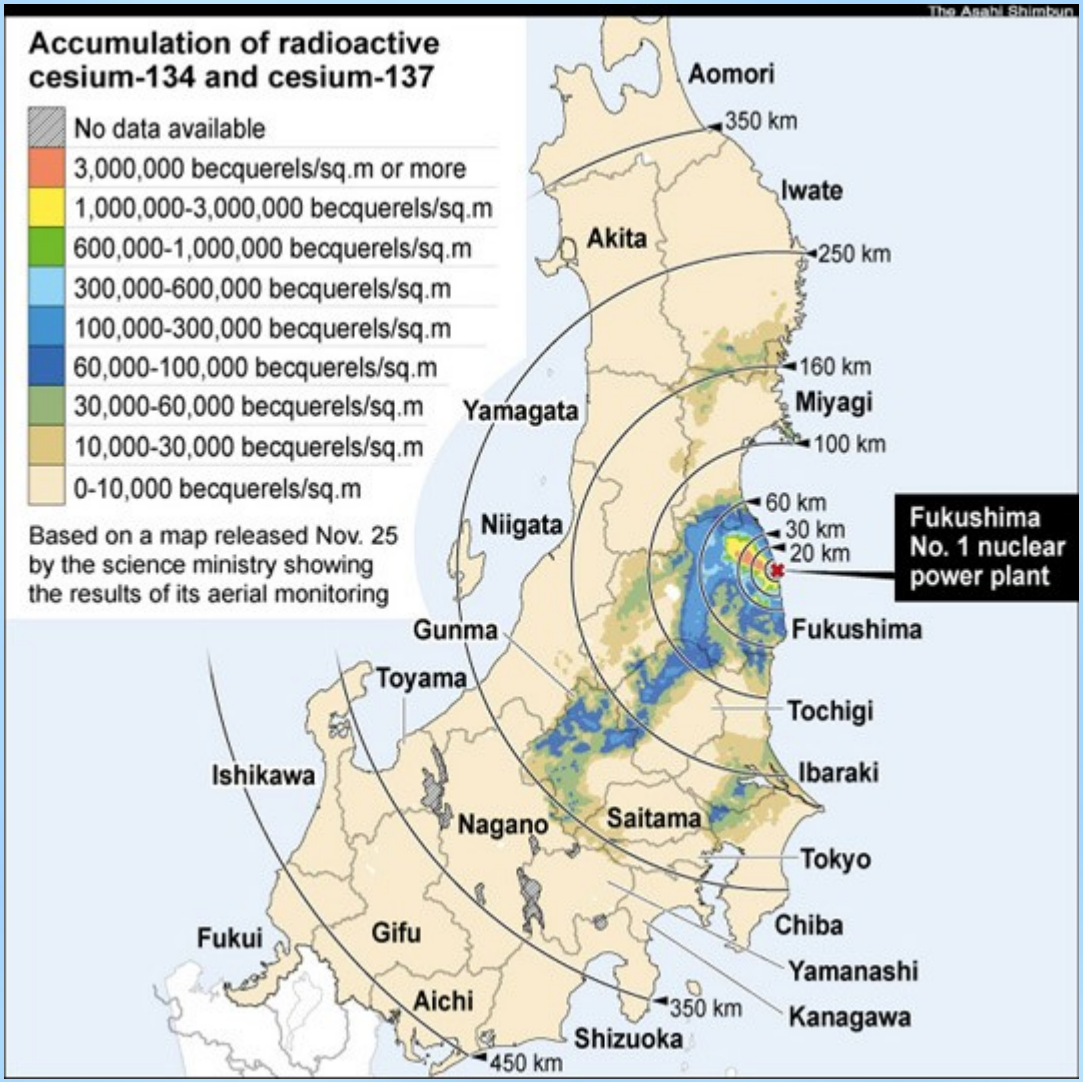
Fission Products (examples)

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

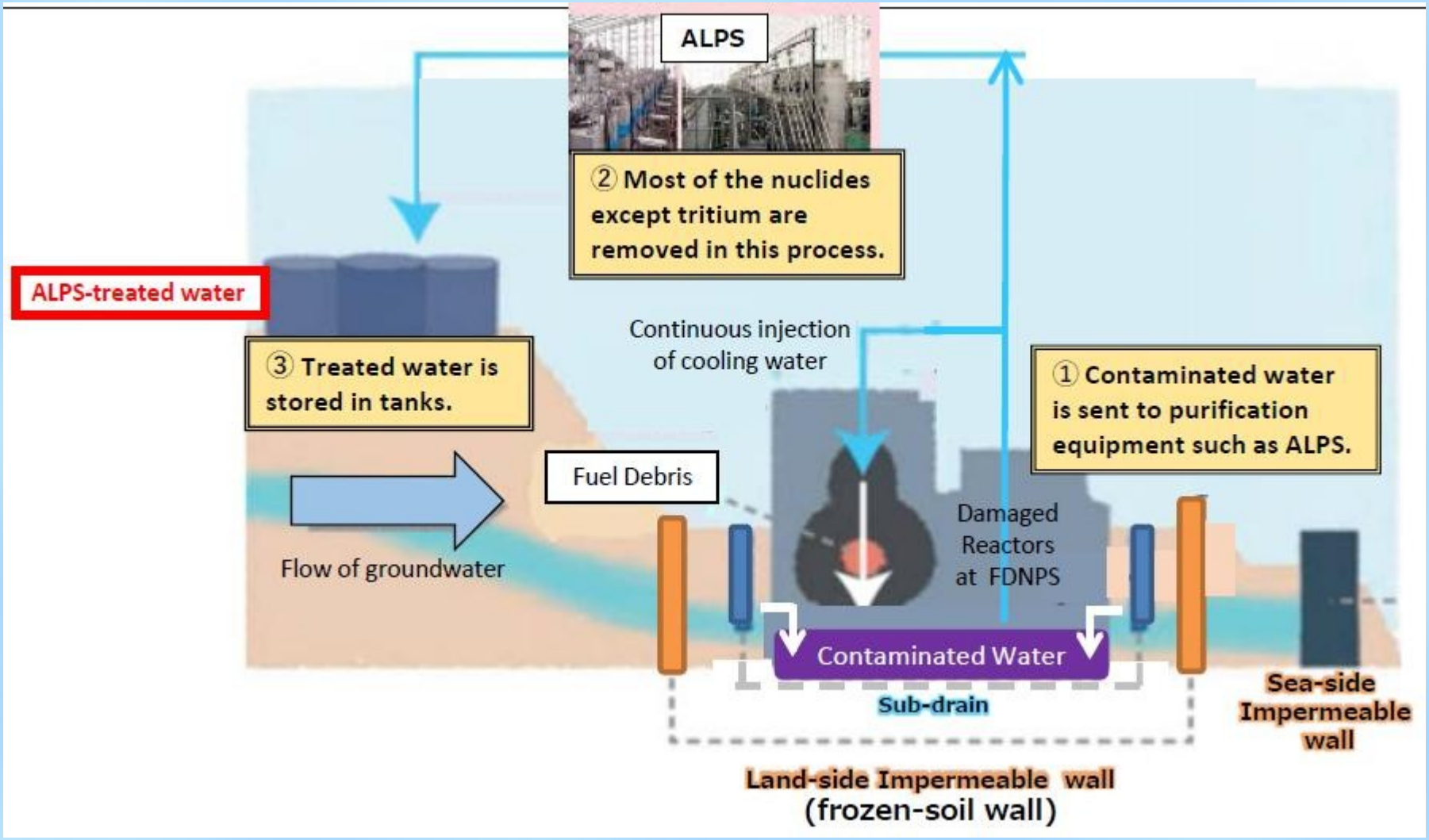
Fukushima Daiichi – Fallout - 1



Fukushima Daiichi – Fallout - 2



Radioactive Water - 1



TEPCO

Radioactive Water - 2

- 10 years after the disaster, water is still being pumped in to cool Reactors 1-3 and the melted down ‘corium’ beneath them
- Also groundwater runs downhill, past the ‘corium’. Both pick up radioactive materials. Total waterflow was ~ 490 t/day
- Later some groundwater was diverted by a land side ‘ice wall’, costing the public $ 320 million and consuming 44 million kWh/y
- The reduced waterflow of ~ 110 t/day is processed by the ALPS cleanup plant.
- The water still contains Tritium, an isotope of Hydrogen that it cannot remove. The half-life is 12.3 years
- So the water has to be stored in steel tanks.

Radioactive Water - 3

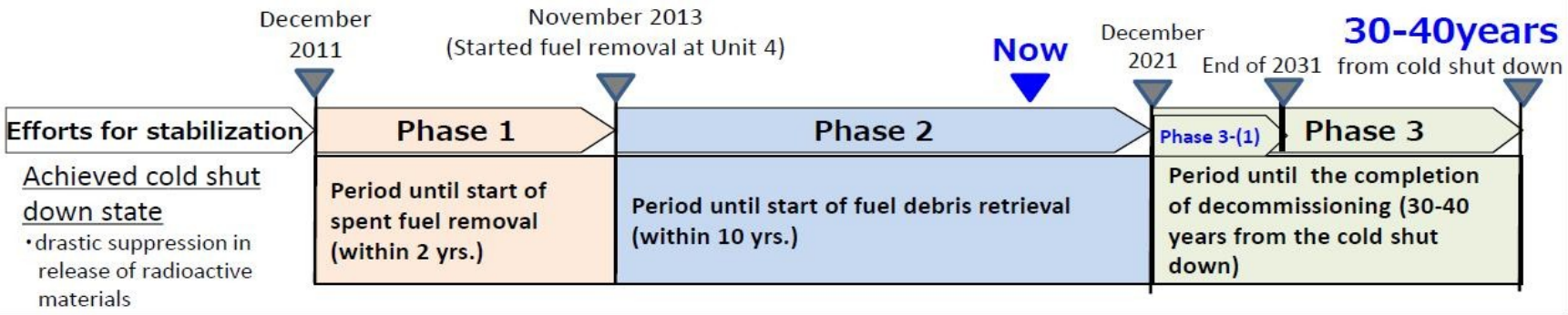
- 10 years after the disaster, with around 1000 water tanks filled, containing about 1 million tonnes, space will run out by 2022.
- A panel has proposed releasing the tritiated water into the sea
- But this is resisted by fisherfolk, whose livelihood was destroyed by the original disaster, and has only slowly recovered
- Also the tritiated water would enter the food chain - seaweed, fish and shellfish - increasing the radioactivity. (Japan limit 100 Bq/kg)
- The health effects of eating such seafoods is disputed.
- But the European Committee on Radiation Risk (ECRR) says that there is no safe limit and the internal health effects - cancers, deaths and genetic - are ~ 1000 x those for external exposures

Decommissioning - 1

1. The Mid-and-Long-Term Roadmap

- Decommissioning of Fukushima Daiichi NPS will be done by TEPCO in its responsibility.
- The decommissioning is an **unprecedented work with technical challenges**. **The Government of Japan has been taking initiative based on the Mid-and-Long-Term Roadmap**, with the target of the completion of decommissioning in 30-40 years in a safe and steady manner.

Time flame for Fukushima Daiichi Decommissioning



Role of the Government of Japan

- **GOJ sets the Roadmap**
  - The Inter-Ministerial Council for Contaminated Water and Decommissioning Issues has set out the Roadmaps. (Chairman: **Chief cabinet secretary**, First version: Dec. 2011)
  - Revised for **five times** to date (Revised in July 2012, June 2013, June 2015, Sept. 2017, Dec. 2019)

- Based on the "Roadmap", mid-and long-term measures has been undertaken while **giving top priority to the safety and keeping the attitude to value the risk reduction.**

1

Decommissioning - 2

- Used fuel in reactors or pools pose high risks as loss of cooling could cause overheating and huge radioactive releases
- TEPCO has emptied the pool of R4, which was offline, no fuel
- Emptying of R3 pool with 566 fuel rods is due to end in 03/2021
- Removal from R2 pool with 615 is due to start in 2024-2026
- Removal from R1 pool with 312 is due to start in 2027-2028
- All pools are due to be emptied by 2031, with fuel transferred to dry casks for safer storage
- Of the three meltdowns, R2 may be of 237 t and R1 + R3, 880 t But such debris has never been removed before

Health Effects - Institutions

- The International Atomic Energy Authority (IAEA) promotes nuclear power
- The World Health Organization (WHO) has deferred to the IAEA
- The US Nuclear Regulatory Commission (NRC) and the UK Office for Nuclear Regulation (ONR) are too close to the nuclear industry
- The Biological Effects of Ionizing Radiation (BEIR) was set up by the US National Academy of Sciences
- The International Committee on Radiation Protection (ICRP) evolved from the US Committee on Radiation Protection
- Only the European Committee on Radiation Risk (ECRR) is independent of nuclear interests

Health Effects of Releases

Magnitudes of Prompt and Latent Cancers and Deaths

Evidence from Atom Bombs, Testing and Chernobyl

Effects of this last were minimised by IAEA-WHO

Yet evidence from Chernobyl is in over 30,000 reports

Best summary in English is Yablokov et al, 2009

Latent Deaths 1986 to 2004 is put at 985,000

Radiation also damages DNA, leading to still-births and genetic deformities, including in all future generations

Health Effects - Evidence

Interpretation of the evidence on health effects of ionizing (nuclear) radiation after Chernobyl, 1986, differs markedly

Date	Author	Model	Excess Deaths
2005	IAEA, WHO	ICRP	4000, 9000 for FSU to 2006
2011	IPPNW-GfS	ICRP	10,000 – 25,000
2006	Fairlie & Sumner	ICRP	30,000 – 60,000 worldwide
1994	Gofman	Gofman	475,000 worldwide
2009	Yablokov et al	Y. et al	985,000 to 2004
2011	Busby	ECRR	740,000–1,480,000 cancers, 50y
2006	Bertell	Bertell	899,600 – 1,787,000 eventual
2011	Busby	Tondell	2,450,000 cancers in 50 y

Fukushima Latent Health Effect Estimates

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

Readiness for Nuclear Disasters

Off-Site Centre some distance away, with air filtration

Thermal Model to predict progression of LOCA

Requires monitoring of Temperatures & Radioactivity on & near site

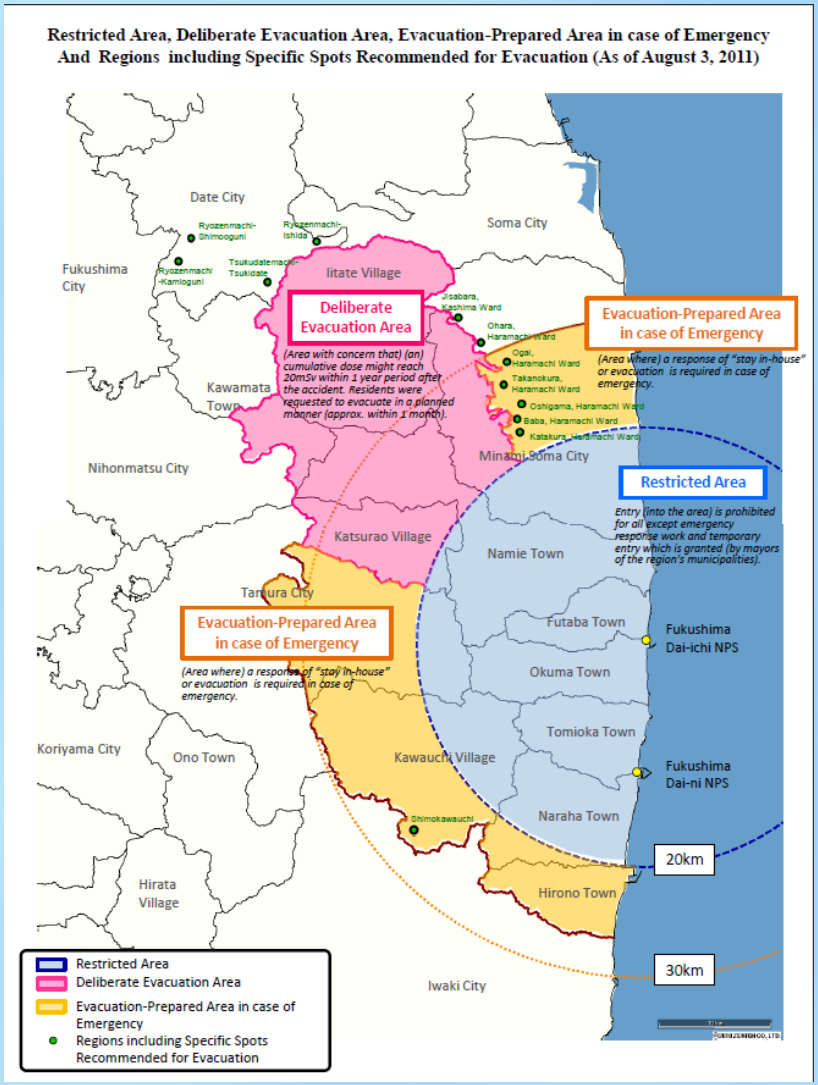
Plume Model to estimate path of Radioactive Release

Requires Real-Time Weather Data – wind speed, direction & rain

Communicate the Plume Model Output to Local Authorities

To inform the Populace about Evacuation Areas and Routes

Fukushima Daiichi – Evacuation Areas



Worst Cases

Nuclear Releases to date are far short of worst case

Effect of larger Reactors

Effect of Multiple Reactors

Effect of Spent Fuel Pools

Effect of larger Release Fractions

Effect of release passing over larger populations

Fallout depends on wind speed, direction and rainfall

The Kondo Report - 1

Following the explosions and radioactive releases at Fukushima on and after 2011-03-12, the then Prime Minister of Japan, Naoto Kan, required Shunsuke Kondo, Chairman of the Japan Atomic Energy Commission, to report on the 'worst case' scenario.

This was delivered in late March 2011. It was not made public, but was reported in the Asahi Shimbun on 2012-01-07. The whole text was included in the 2012-02-28 report of the private panel on the Fukushima disaster chaired by Koichi Kitazawa.

The Kondo Report - 2

The Kondo Report - 3

The Kondo Report - 4

The 'worst case' scenario would require:

- Mandatory evacuation of all within 170 km

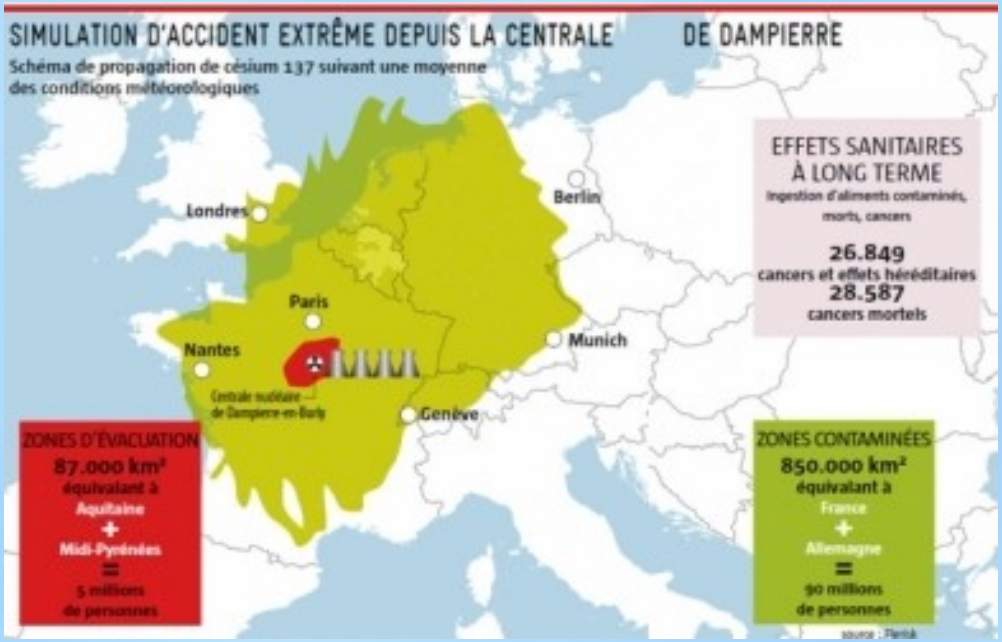
- 'Voluntary' evacuation of all within 250 km

These include Fukushima City, with 290,000,
Sendai, with 1 million
and Tokyo, with 35 million

The Momal Report

Evacuated: 85,000 km2, 5 million, € 475 bn

Polluted: 850,000 km2, 90 million, € 4400 bn



Matthieu Pechberty - Le Journal du Dimanche, 10 mars 2013

Nuclear Releases – Actual and Worst Cases

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

Probabilities

Originally Risk was taken as Consequence

Later Risk was taken as Consequence x Probability

But Probabilistic Safety Analysis requires:

- Identification of accident sequences (billions)
- Probabilities for each unit in sequence (most are unknown)

In practice, far fewer sequences are considered

So the overall Probability must be an under-estimate

And is not just unknown, but unknowable

Hence Probability must be taken as 1 – i.e. inevitable

And Risk must be taken as Consequence

Insurance and Ethics

- From the beginning of civil nuclear power in 1954, the worldwide insurance industry refused to provide complete cover
- The operators' interests were secured by limiting their liability with the Paris Convention of 1960 and the Vienna Convention of 1963
- These were prompted by US Price-Anderson Act of 1957 and followed by the UK Nuclear Installations Act of 1965 whereby, apart from a nominal amount, the risk is carried by the State
- Such 'Statutory Indemnities' are 'unquantifiable' – i.e. infinite
- The Versicherungsforen Leipzig found in 2011 that the mean sum payable for a nuclear disaster could be € 6090 billion
- The German Ethics Commission found in 2011 that withdrawal from nuclear energy is necessary, recommended and possible because there are less risky alternatives

Human Factors - 1

- There has been gross negligence for over 50 years by all npp operating companies and all the nuclear safety agencies
- The Fukushima disaster was aggravated by the personnel being responsible for multiple reactors under emergency conditions
- There had been no testing or drills of SBOs and LOCAs
- Once meltdowns and releases had occurred, they had no means of mapping the fallout to guide evacuation, and had to rely on US military based in Japan
- With the future of Japan at stake, the possibility of withdrawal of the 250 workers lead to PM Kan going to TEPCO to forbid it
- To provide emergency cooling, firefighters were summoned from Tokyo, but – in view of the dangers - limited to those over 40

Human Factors - 2

- The later Abe government has coerced ‘voluntary’ evacuees to return by stopping their housing subsidies after only six years. Many still resist returning, despite the hardships
- The Abe government has encouraged the restart of the 39 remaining operable npps, but succeeded with only a few. Nuclear power is still strongly resisted by most Japanese people
- The Abe government has put back the date for clearing the used nuclear fuel that still requires cooling. Meanwhile any loss of cooling risks more disastrous radioactive releases
- There is a shortage of workers to do the cleanup. This is sub-contracted to companies who hire vulnerable people, and will continue for another 30 years. The Abe government eased the immigration laws to bring in workers who are evidently seen as expendable. The Russians call such people ‘human robots’

The Real Lessons - Summary

The IAEA and ONR reports lack detail and data

Deaths may be 350-3000 or 10,000 - 200,000

Contaminated land may be 13,000 - 30,000 km^2

The plume passed over Tokyo, but it did not rain

UK siting criterion is 30 km, but Kondo is 250 km

The Real Lessons of Fukushima - 1

- Many quantitative studies have been found, but no proper studies from the IAEA or the UK ONR.
- Plume models of radioactive releases are essential to inform evacuations. The Japanese have such a plume model, SPEEDI, but it was ignored until later.
- Also they had no instrument for airborne radioactivity measurements and had to rely initially on aerial surveys carried out by the US military.
- Yet these deficiencies were omitted or downplayed in the reports of the IAEA Fact Finding Mission.

The Real Lessons of Fukushima - 2

- Nearly 15,000 workers have received doses of up to 250 mSv.
- About 85,000 were forced to evacuate, and 70,000 chose to. Yet the cost of housing the latter is being withdrawn.
- Excess cancers and resulting deaths may take up to 50 years to appear. Depending on the dose-effect model assumed, these may be 350 to 3000 or 10,000 to 200,000.
- Radioactivity above Japanese government limits has been found in many foods. This 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 Real Lessons of Fukushima - 3

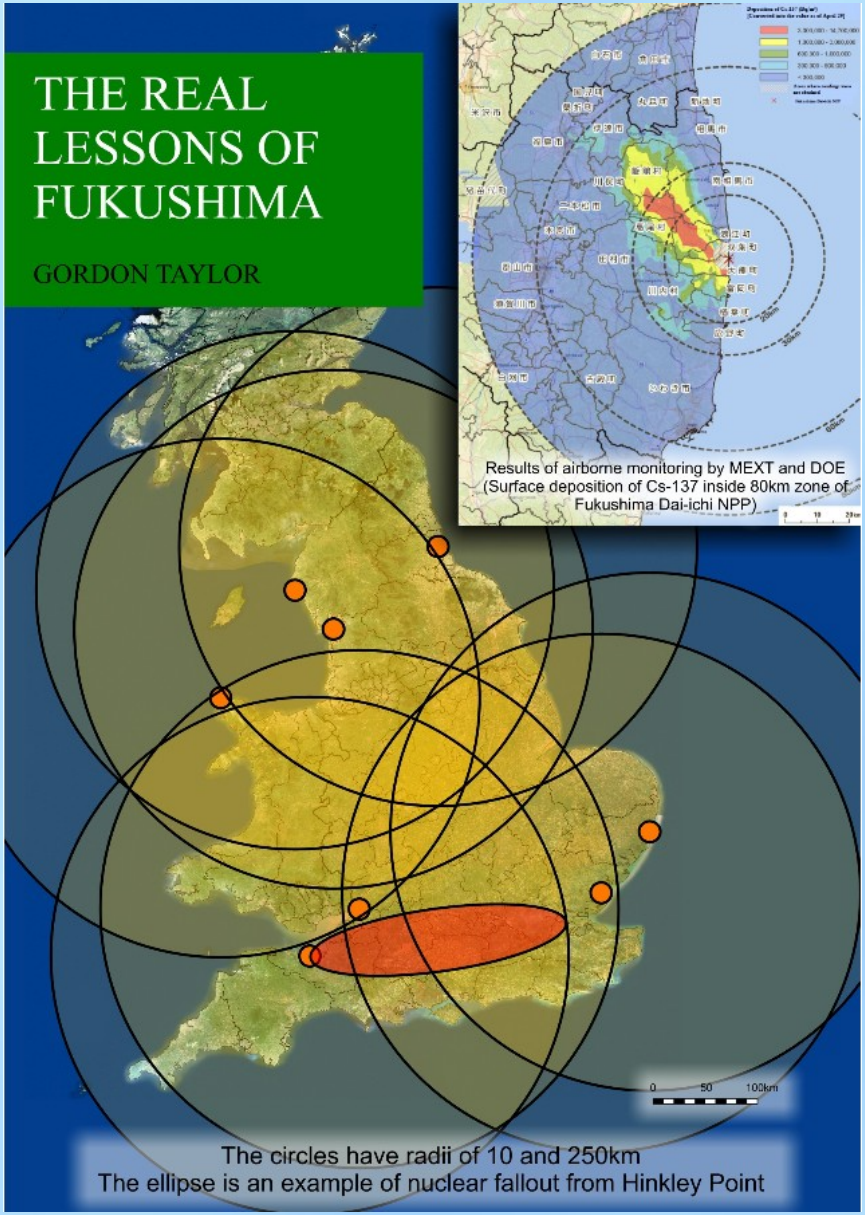
- The area of land contaminated with radioactive cesium to more than 10,000 Bq/m^2 is about 30,000 km^2, some 8% of the land area of Japan. Part of this will be uninhabitable for 10 to 20 years or more.
- According to the decontamination plan, the land area for which the dose to humans would be over 1 mSv/y is about 13,000 km^2.
- The cost of the decontamination measures have been estimated at from 1.2 to more than 10 trillion yen ($130 billion).
- Yet the insurance fund available is only about 120 billion yen ($ 1.6 billion) per nuclear plant. Since TEPCO is virtually bankrupt, almost all the cost must be met by all the electricity users or by taxpayers.
- Such costs for actual and worst cases are extortionate and mean that nuclear power can never be competitive.

The Real Lessons of Fukushima - 4

- 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 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, as in the Kondo Report, have consequences that are even more horrific.
- Japan shut down all the nuclear power plants. Later the government forced the restart of a few, against citizen opposition.
- Germany, Switzerland and Italy have decided to join most other countries and phase out nuclear power.

The Real Lessons of Fukushima - 5

- 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 Nuclear Installations Inspectorate 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 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'.


THE REAL LESSONS OF FUKUSHIMA
GORDON TAYLOR
Results of airborne monitoring by MEXT and DOE
(Surface deposition of Cs-137 inside 80km zone of Fukushima Dai-ichi NPP)
0 50 100km
The circles have radii of 10 and 250km
The ellipse is an example of nuclear fallout from Hinkley Point

Rational Energy Policy - Questions

- Oil is used for transport, gas and coal for heat and power, but what is electricity used for ?
- How much less energy could be used for all these services ?
- In the UK, electricity is 20% of energy

  and nuclear is 20% of electricity = 4% of energy, so what will replace the (depletable) uranium ?
- What will replace the 96% that is gas, oil, & coal ?

Rational Energy Policy - Answers

- After a major nuclear release, all nuclear plants may be shut down – as happened after Fukushima
- As the consequences are completely unacceptable, all nuclear power plants should be phased out
- Others are moving to supplying all energy services with increased energy efficiency and renewables
- These are safe, robust (not subject to disastrous events with huge consequences) and sustainable
- Japan generates 23% from renewables – 3 x from npps

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Reports with References are at:

www.energypolicy.co.uk/TheCaseAgainstNuclearPower.pdf

and

www.energypolicy.co.uk/FukushimaRealLessons.pdf

More presentations and papers on energy are at: