SafetyInEngineering

Fukushima and its consequences

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Fukushima and its consequences

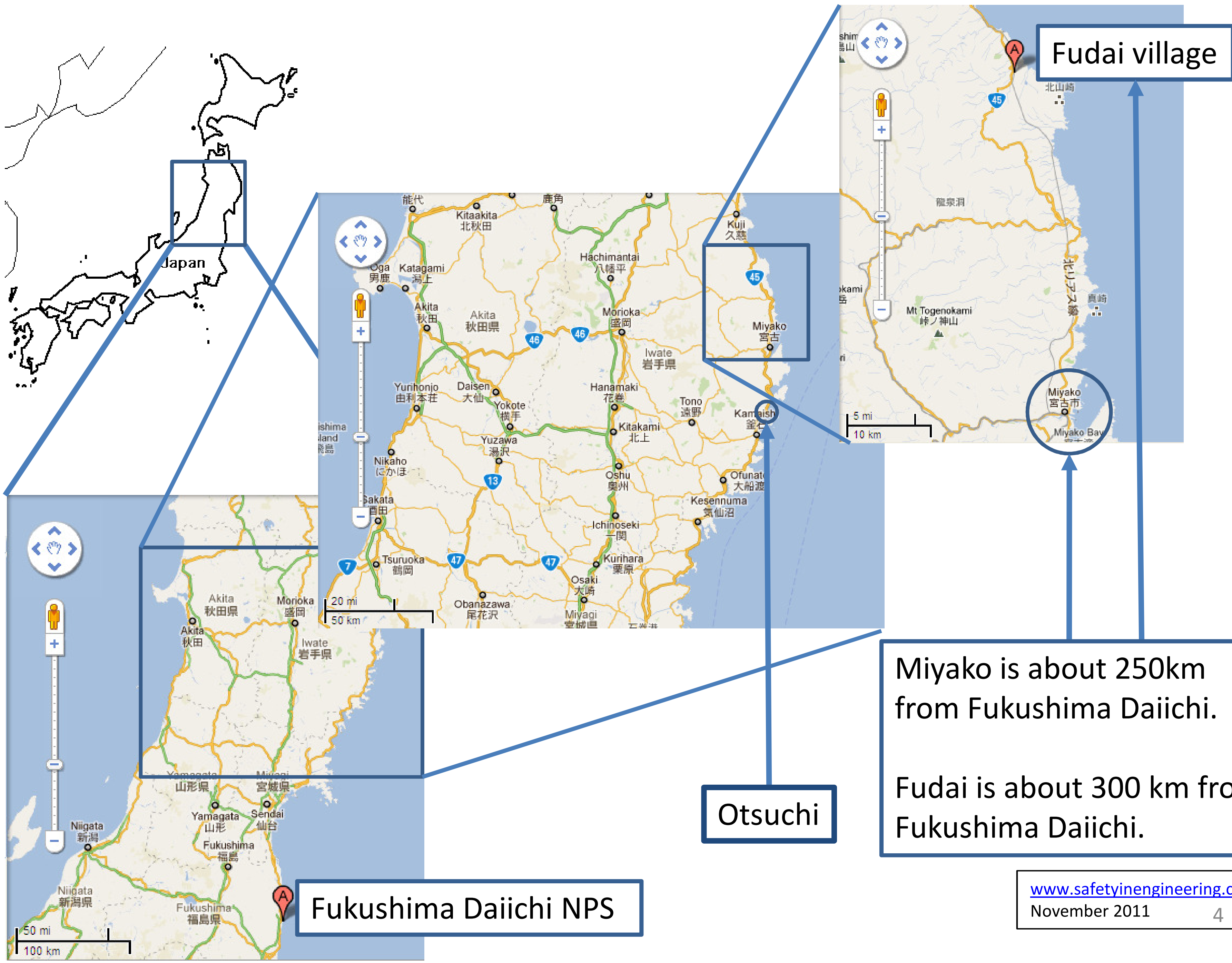
1. The wider effects of the earthquake and tsunami
2. Events at Fukushima Daiichi
3. Lessons learned
4. Health and environmental consequences
5. Emergency planning
6. Delays to new build

The earthquake, tsunami and aftershocks

Friday 11th March, 2.46pm: The initial earthquake was about magnitude 9. The tsunami struck some 26 minutes later. In the time between the earthquake and the first tsunami, multiple seismic events some with magnitudes between 6.4 and 7.9 occurred within 100 km of the initiating event. Aftershocks as big as magnitude 7 continued for days.

"The total inundated area was up to 561 km^2 ....
The total number of residential buildings damaged was approximately 475,000 including fully-destroyed, half-destroyed, partially-destroyed and inundated structures. The number of cases of damage to public buildings and cultural and educational facilities was as many as 18,000.......
In addition, approximately 460,000 households suffered from gas supply stoppages, approximately 4,000,000 households were cut off from electricity, and 800,000 phone lines were knocked out.......
24,769 people have been reported as dead or missing."

From the Japanese Government's interim report, June 2011
http://www.kantei.go.jp/foreign/kan/topics/201106/iaea_houkokusho_e.html



Miyako is about 250km from Fukushima Daiichi.

Fudai is about 300 km from Fukushima Daiichi.

Miyako City

"The tidal embankment in the Taro area of Miyako City in Iwate Prefecture is referred to locally as the "Great Wall of China" as it towers 10 meters high. However, even this collapsed when hit by a tsunami that was 15m high, or possibly higher, and significant damage occurred within the embankment ." From the Japanese Government's report, June 2011

According to Wikipedia, the tsunami reached 37.9m in Miyako and killed 401 people. Only 30 of the town's 1000 fishing boats survived. Some of the iconic tsunami video was taken in Miyako – see http://www.youtube.com/watch?v=0wYiNnHEGyY

Aneyoshi stone monument

"In the Aneyoshi area, Miyako City in Iwate Prefecture, there is a stone monument with the warning not to build houses in the area lower than that point as shown at the entrance (height 60 m) of the village, showing lessons learned from run-ups of the two historical tsunamis ...... By observing this lesson, the area was able to avoid casualties this time even though the tsunami ran up (the actual run-up height was 38.9 m) near the village as shown........" From the Japanese Government's report, June 2011

Aneyoshi

(*NY Times,*
20th April 2011)

“Do not build your homes below this point!” Residents say this injunction from their ancestors kept their tiny village of 11 households safely out of reach of the deadly tsunami last month that wiped out hundreds of miles of Japanese coast and rose to record heights near here.

Hundreds of so-called tsunami stones, some more than six centuries old, dot the coast of Japan............... But modern Japan, confident that advanced technology and higher seawalls would protect vulnerable areas, came to forget or ignore these ancient warnings, dooming it to repeat bitter experiences when the recent tsunami struck............

Some stones were swept away by last month’s tsunami, which scientists say was the largest to strike Japan since the Jogan earthquake in 869, whose waves left sand deposits miles inland.

Miyako

Harbour area where iconic 'black wall of water' video was taken

Road destroyed

Aneyoshi

(marker stone)

Fudai village

"……..the 15.5 m embankment was installed in the Ootabu area, Fudai village in Iwate Prefecture following a strong desire of the village chief *(sic)* learning from previous experiences with tsunami. This embankment was able to resist the 15m tsunami and prevented the damage within the embankment zone…….. These areas are rias type coastlines that have, historically, suffered significantly from giant tsunamis in the 15m range such as the Meiji Sanriku Tsunami (1896) and the Showa Sanriku Tsunami (1933), the lesson of preparation against a 15m-class tsunami has been instructed *(sic).* …… Against these tsunamis, there was a sharp contrast between the Ootabe area, which heeded the lessons of the past, and the Taro area." From the Japanese Government's report, June 2011

Fudai village (*AP report 13th May 2011*)

In the rubble of Japan's northeast coast, one small village stands as tall as ever after the tsunami. No homes were swept away. In fact, they barely got wet. Fudai is the village that survived — thanks to a huge wall once deemed a mayor's expensive folly and now vindicated as the community's salvation.

The 3,000 residents living between mountains behind a cove owe their lives to a late leader who saw the devastation of an earlier tsunami and made it the priority of his four-decade tenure to defend his people from the next one. His 51-foot (15.5-meter) floodgate between mountainsides took a dozen years to build and meant spending more than $30 million in today's dollars........

In Fudai, the waves rose as high as 66 feet (20 meters), as water marks show on the floodgate's towers.

The man credited with saving Fudai is the late Kotaku Wamura, a 10-term mayor whose political reign began in the ashes of World War II and ended in 1987. But Wamura never forgot how quickly the sea could turn. Massive earthquake-triggered tsunamis flattened Japan's northeast coast in 1933 and 1896. In Fudai, the two disasters destroyed hundreds of homes and killed 439 people.

"When I saw bodies being dug up from the piles of earth, I did not know what to say. I had no words," Wamura wrote of the 1933 tsunami.

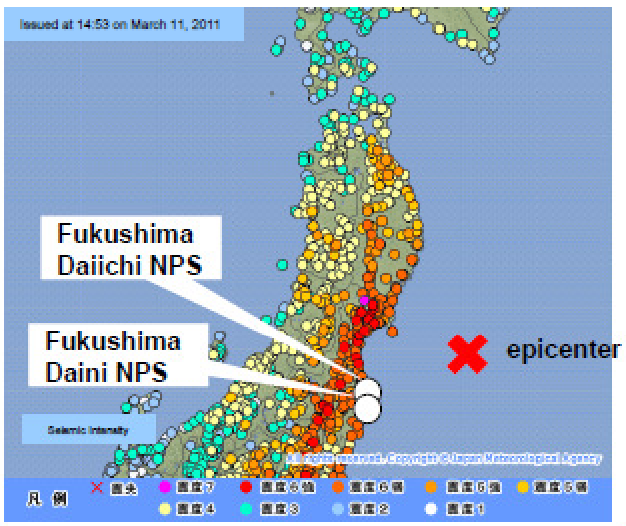
Otsuchi

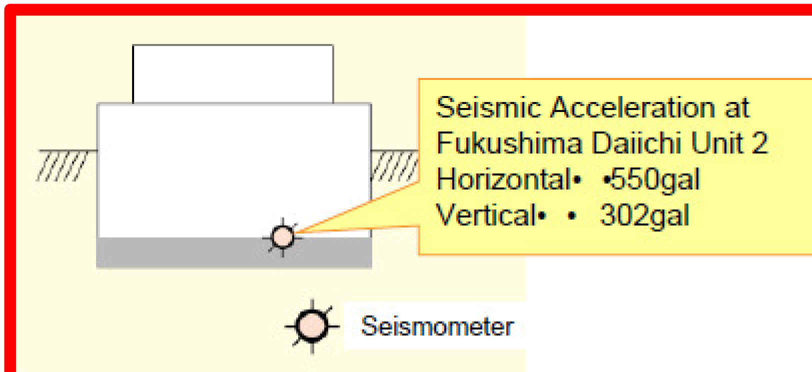
Source: TEPCO status report, 4th October 2011, from www.tepco.co.jp

Tohoku Pacific Ocean Earthquake

- **Time:** 2:46 pm on Fri, March 11, 2011.
- **Place:** Offshore Sanriku coast (northern latitude of 38 degrees, east longitude of 142.9), 24km in depth, Magnitude 9.0
- **Intensity:** **Level 7** at Kurihara in Miyagi Miyagi prefecture
  Upper 6 at Naraha, Tomioka, Okuma, and Futaba in Fukushima pref.
  Lower 6 at Ishinomaki and Onagawa in Miyagi pref., Tokai in Ibaraki pref.
  Lower 5 at Kariwa in Niigata pref.
  Level 4 at Rokkasho, Higashidori, Mutsu and Ohma in Aomori pref., Kashiwazaki in Niigata pref.

• Epicenter• •





* gal: a unit of acceleration defined as cm/s².

Other NPPs shut down safely

- Other NPPs on the north-east coast of Honshu shut down safely.
- These included Onagawa (3 units), Fukushima Daiini (4 units), and Tokai (1 unit).

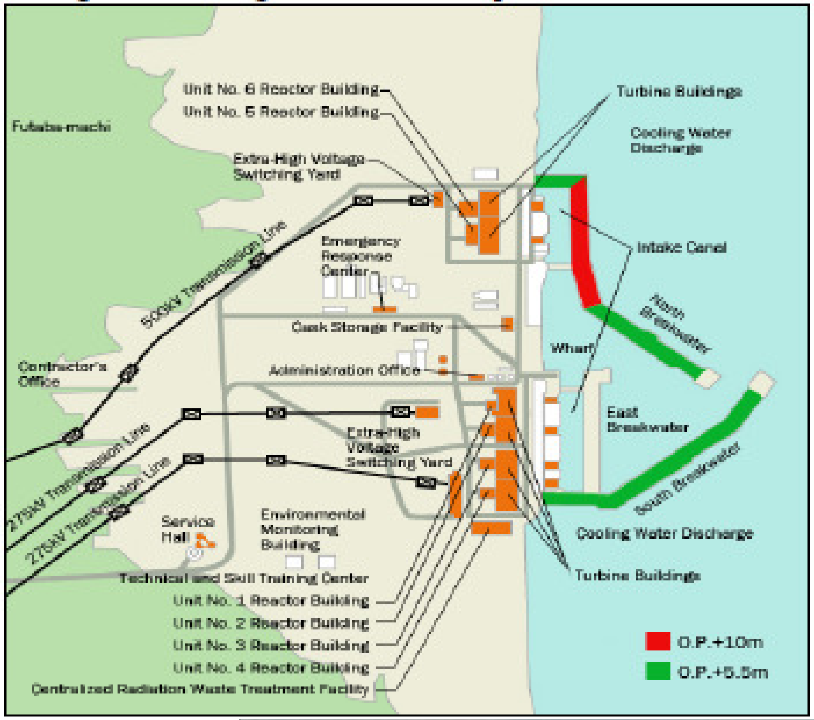
Executive summary from INPO report, November 2011

- On March 11, 2011, at 1446 (JST), a severe earthquake measuring 9.0 on the Richter Scale occurred 112 miles (180 km) off the coast of the Fukushima Daiichi Nuclear Power Station. ***The earthquake was the largest Japan has ever experienced. It caused all of the operating units (units 1, 2, and 3) to automatically scram on seismic reactor protection system trips.*** The earthquake damaged breakers and distribution towers, causing a loss of all off-site electrical power sources to the site. ***The emergency diesel generators automatically started and provided AC power to emergency systems.*** Three minutes after the earthquake, the Japan Meteorological Association issued a major tsunami warning, indicating the potential for a tsunami at least 3 meters high. ***Station workers were notified of the warning and evacuated to higher ground.***
- Forty-one minutes after the earthquake, at 1527, the first of a series of seven tsunamis arrived at the site. ***The maximum tsunami height impacting the site was estimated to be 46 to 49 feet (14 to 15 meters). This exceeded the design basis tsunami height of 18.7 feet (5.7 meters) and was above the site grade levels of 32.8 feet (10 meters) at units 1-4. All AC power was lost to units 1-4 by 1541 when a tsunami overwhelmed the site and flooded some of the emergency diesel generators and switchgear rooms.*** The seawater intake structure was severely damaged and was rendered non-functional. All DC power was lost on units 1 and 2, while some DC power from batteries remained available on Unit 3. Four of the five emergency diesel generators on units 5 and 6 were inoperable after the tsunami. One air-cooled emergency diesel generator on Unit 6 continued to function and supplied electrical power to Unit 6, and later to Unit 5, to maintain cooling to the reactor and spent fuel pool.

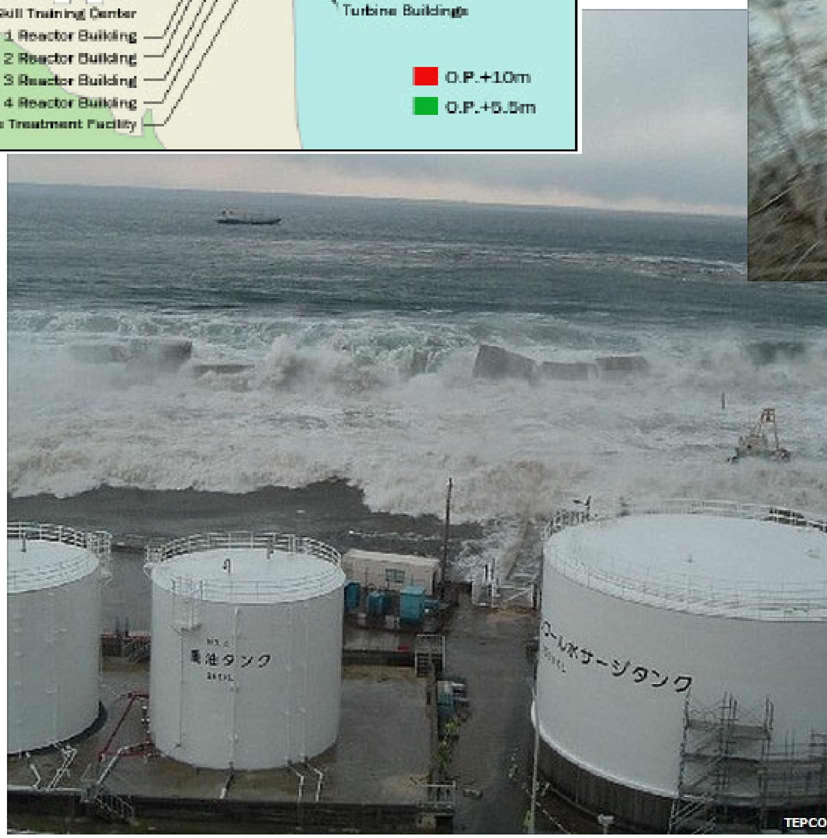
Taken from: *INPO 11-005 November 2011, Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station*

Executive summary from INPO report, November 2011 (continued)

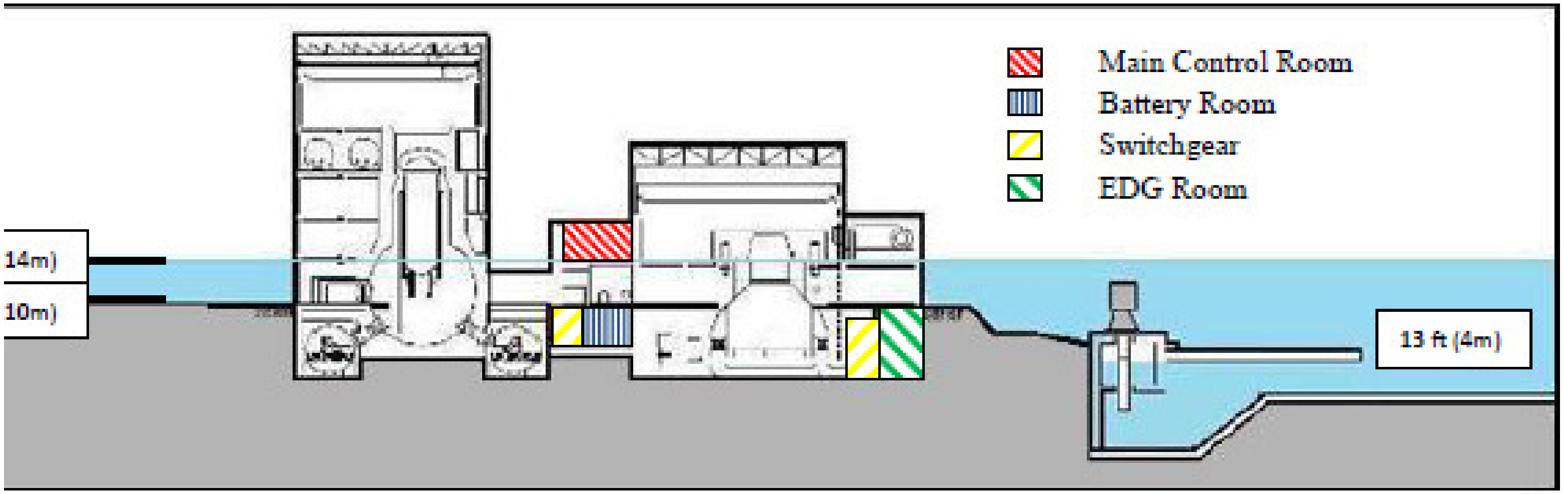
- ***With no core cooling to remove decay heat, core damage may have begun on Unit 1 on the day of the event.*** Steam-driven injection pumps were used to provide cooling water to the reactors on units 2 and 3, but these pumps eventually stopped working; and all cooling water to the reactors was lost until fire engines were used to restore water injection. ***As a result of inadequate core cooling, fuel damage also occurred in units 2 and 3. Challenges in venting containments contributed to containment pressures exceeding design pressure, which may have caused containment damage and leakage.***
- ***Hydrogen generated from the damaged fuel in the reactors*** accumulated in the reactor buildings either during venting operations or from other leaks and ignited, producing ***explosions in the Unit 1 and Unit 3 reactor buildings*** and significantly complicating the response. The hydrogen generated in Unit 3 may have migrated into the Unit 4 reactor building, resulting in a subsequent explosion and damage. The loss of primary and secondary containment integrity resulted in ground-level releases of radioactive material. Following the explosion in Unit 4 and the abnormal indications on Unit 2 on the fourth day of the event, the site superintendent directed that all nonessential personnel temporarily evacuate, leaving approximately 70 people on site to manage the event.


Unit No. 6 Reactor Building
Unit No. 5 Reactor Building
Futaba-machi
Extra-High Voltage Switching Yard
Turbine Buildings
Cooling Water Discharge
Emergency Response Center
500kV Transmission Line
Intake Canal
North Breakwater
Cask Storage Facility
Contractor's Office
Administration Office
Wharf
East Breakwater
Extra-High Voltage Switching Yard
275kV Transmission Line
275kV Transmission Line
South Breakwater
Service Hall
Environmental Monitoring Building
Cooling Water Discharge
Turbine Buildings
Technical and Skill Training Center
Unit No. 1 Reactor Building
Unit No. 2 Reactor Building
Unit No. 3 Reactor Building
Unit No. 4 Reactor Building
Centralized Radiation Waste Treatment Facility
O.P.+10m
O.P.+5.5m

INPO


TEPCO

TEPCO


Main Control Room
Battery Room
Switchgear
EDG Room
14m)
10m)
13 ft (4m)

INPO


TEPCO

TEPCO

Source: TEPCO status report, 4th October 2011, from www.tepco.co.jp

Fukushima Daiichi being struck by the tsunami (1)

Taken from near the south side of Unit 5, looking east

Taken from radwaste building 4th floor, looking north

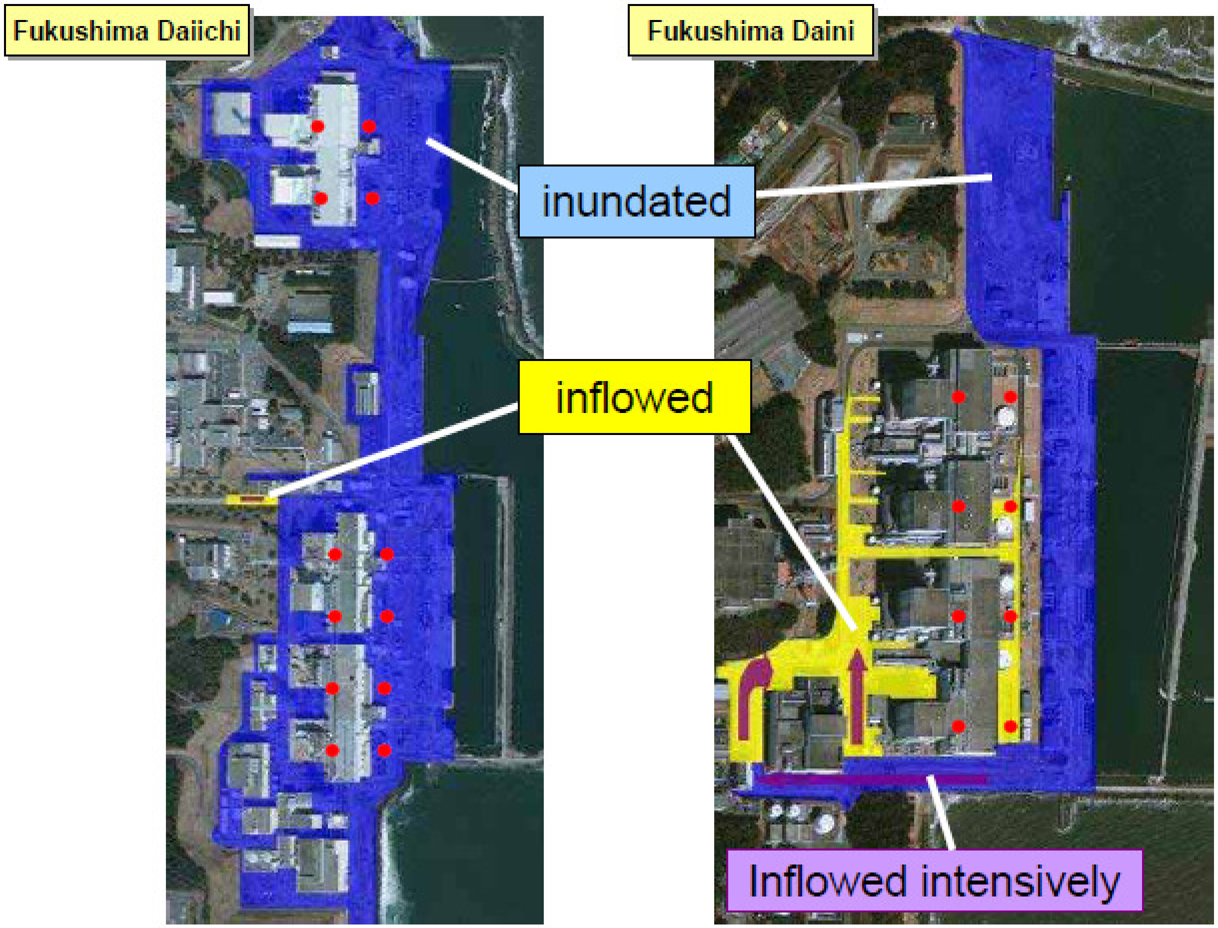
Tank Height about 5.5m

• height of ground : O.P.• 10m• •

O.P.• Onahama bay construction base level

Source: TEPCO status report, 4th October 2011, from www.tepco.co.jp

Inundated and Inflowed Area at Fukushima Daiichi and Daini Site



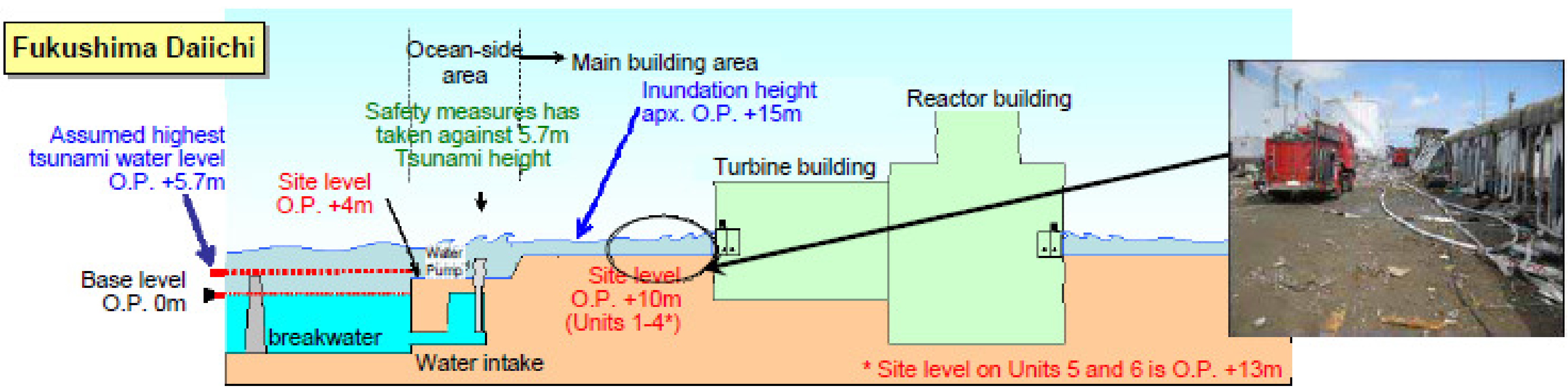
Note: The coastline sank by 1-2 metres because of the earthquake. (Earthquake/ tsunami CMF?)

This was the principal mistake. Everything else was a direct consequence.

Based on the evaluation method by the Japan Society Civil Engineers revised on 2002, we assumed the highest water level of Tsunami as O.P. 5.7m at Fukushima Daiichi and O.P. 5.2m at Fukushima Daini.

Inundation height was approximately O.P. +15m at Fukushima daiichi and approximately O.P. +7m at Fukushima Daini.

Accordingly, we have confirmed that the impact of Tsunami (water level and inundated area) was relatively larger in Fukushima Daiichi Nuclear Power Station than Fukushima Daini Nuclear Power Station.



INPO report extract – tsunami design basis

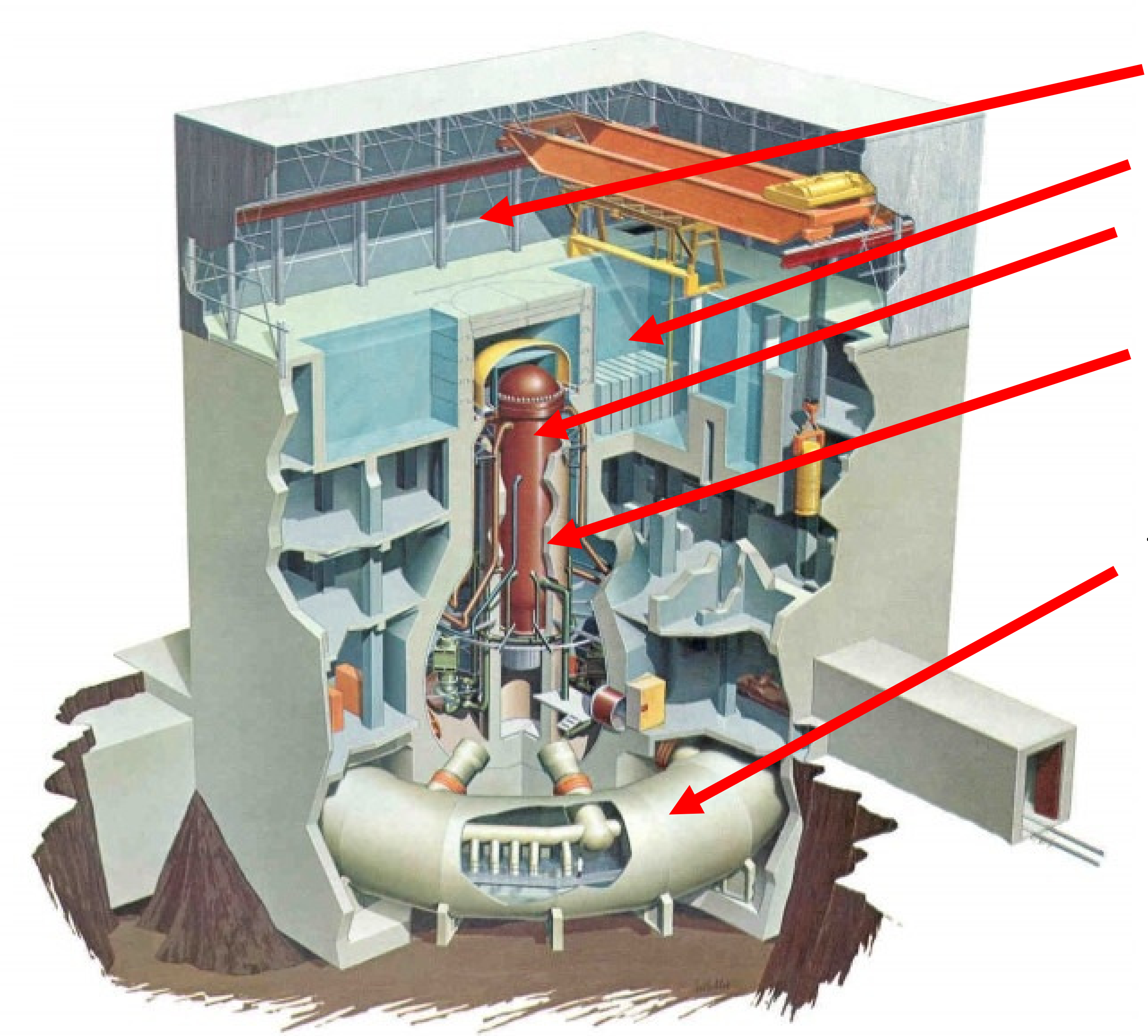
Following the publishing of Tsunami Assessment Methods for Nuclear Power Plants in Japan by the Japan Society of Civil Engineers (JSCE) in 2002, TEPCO voluntarily reassessed its tsunami design basis. Using these new deterministic evaluation techniques, however, TEPCO determined the design basis tsunami would result in a maximum water level of 18.7 ft (5.7 m). Because these changes were done voluntarily and not at the direction of the regulator, the licensing basis did not change. According to the evaluation, the elevation of the Unit 6 seawater pump motor for the emergency diesel generator was raised 7.9 in (20 cm), and the seawater pump motor for high pressure core spray was raised 8.7 in (22 cm). These changes ensured all vital seawater motors were installed higher than the new inundation level of 18.7 ft (5.7m). The new analysis did not consider or require the station design to mitigate hydrodynamic impact forces. The breakwater was not modified when the new tsunami height was implemented because it was not intended to provide tsunami protection, but rather to minimize wave action in the harbor.

Taken from: *INPO 11-005 November 2011, Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station*

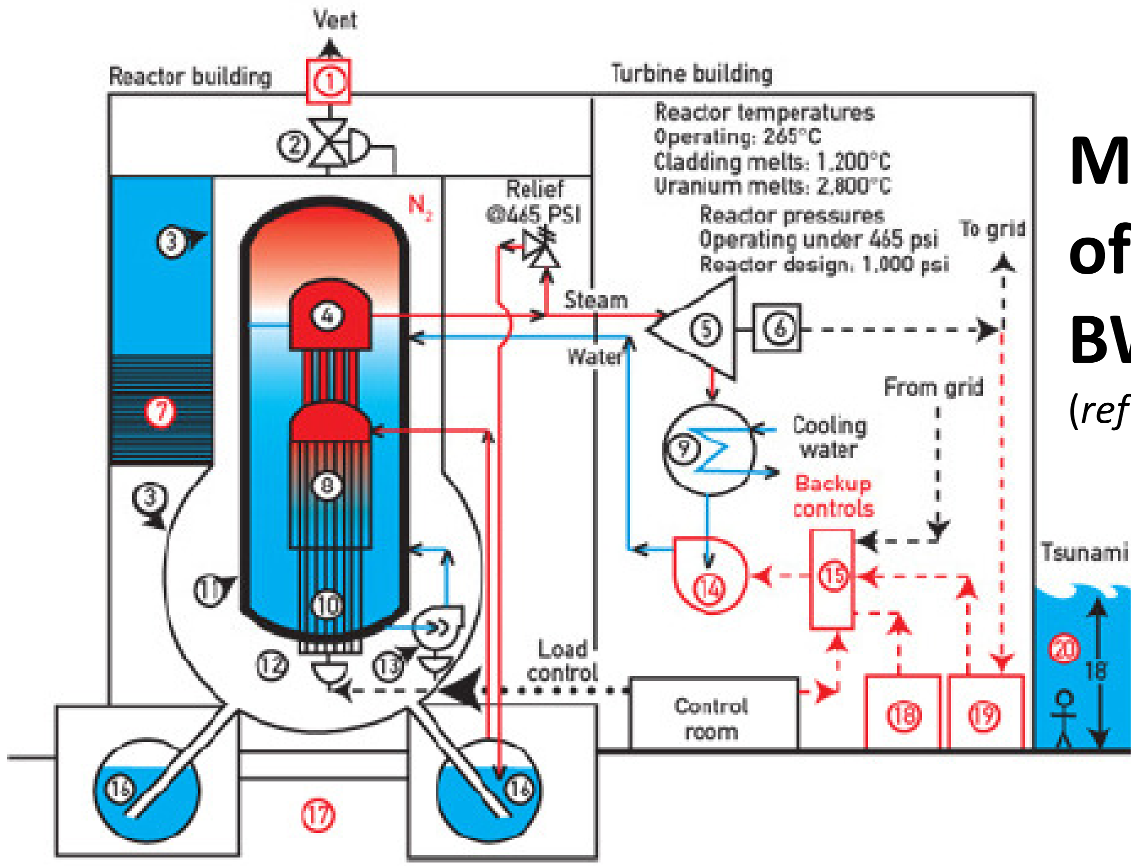
The Japan Times 3rd July

Tokyo Electric Power Co. was aware 10-meter-plus tsunami could hit the Fukushima No. 1 nuclear power station as early as in 2008, reporting the results of simulations for the first time to the Nuclear and Industrial Safety Agency on March 7 — four days before 13-meter waves knocked out the plant.............

A Tepco section chief reported the results to NISA on March 7. NISA officials had pointed out "countermeasures are urgently needed," calling for modifications.



GE BWR Mk 1 Containment (1970's)



Main components of Fukushima Daiichi BWRs

(*ref www.ControlGlobal.com*)

Figure 1: The main components of the Fukushima nuclear power plant (The components numbered in black were designed and operated correctly, the ones in red did not). 1-solids filter, 2-vent valve, 3-primary container or drywell, 4-steam separator & dryer, 5-turbines, 6-generators, 7-spent fuel rod pool, 8-reactor core, 9 -condenser, 10-down-comer region, 11- reactor pressure vessel (RPV), 12-control rods, 13-recirculation pumps, 14-cooling feed-water pumps, 15-back-up selector switch, 16-torus or wet well, 17-core catcher, 18-diesel generator back-up, 19-battery back-up, 20- the height of the tsunami waves reaching the plant

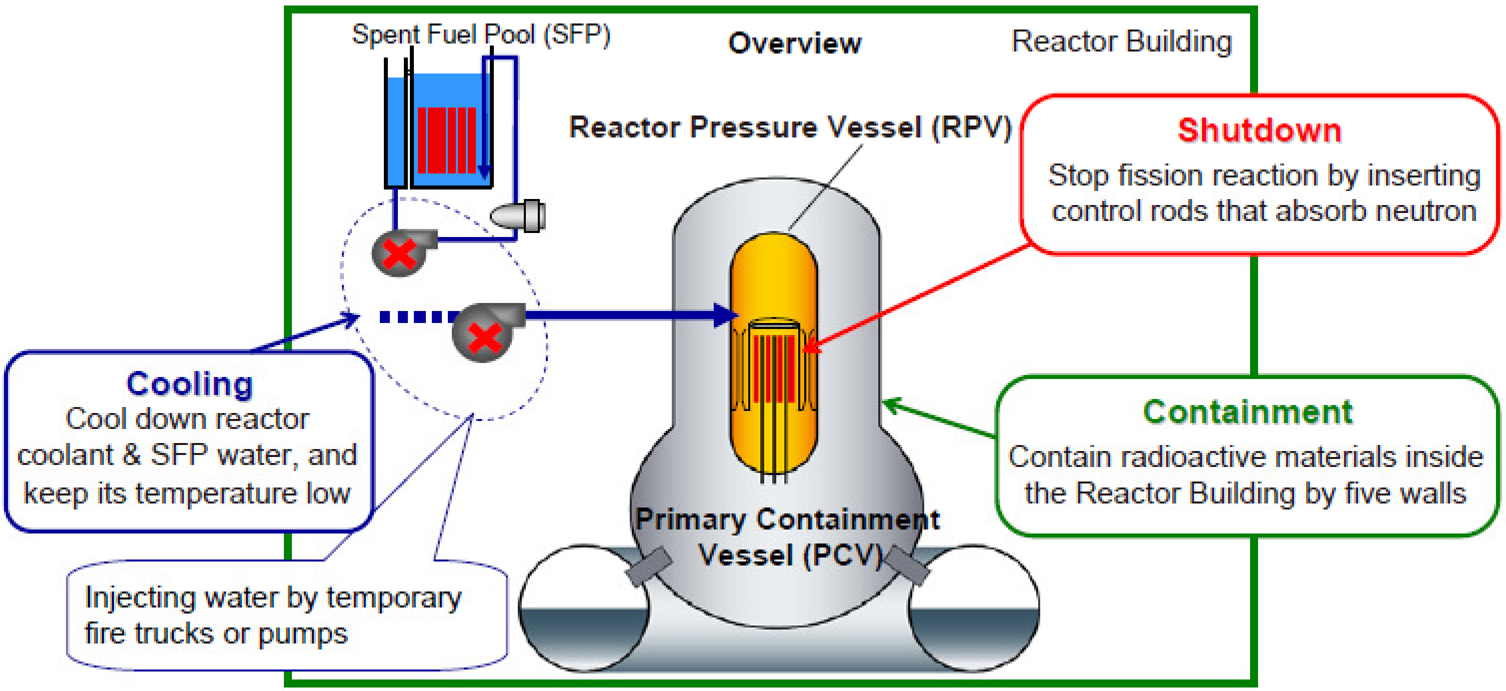
Nuclear reactors – The basic requirements for safety *(you need all three)*

1. **Rapid shutdown on demand** *(control rods)* OK
2. **Reliable post-trip cooling** *(water supply, pumps operable, power supply, back-up diesel generators)* ✗
3. **Robust containment of fission products** ✗

Complete failure of item 2 may lead to failure of item 3 after some time, depending on the design. (Modern designs can maintain containment even after prolonged loss of cooling.)

Impacts for Safety Function

- "Shutdown" was secured by automatic shutdown of all control rods inserted at the same time of the earthquake
- Transmission line was damaged by the quake; diesel generators started but subsequently were lost due to the Tsunami, leading Station Black Out.
- Most of the "Cooling" function of reactor and spent fuel pool were lost by the loss of power supply caused by Tsunami.
- High level contaminated water has been found in turbine buildings, "Containment" function is presumed to be impaired.



Situation facing the power station staff after the tsunami

- The station was cut off from all grid connections;
- Back-up diesel electricity supplies failed and hence all post-trip cooling was inoperative;
- The roads were impassable;
- Communications were poor;
- Station staff will have been concerned about their families and their homes;
- There were ongoing major aftershocks;
- After the batteries ran out (or failed), the power plants were literally blacked-out. Staff could only find their way round the plant using torches. There were no control room screens or other indications of plant state;
- Station staff will have been keenly aware of the time pressures to try to restore post-trip cooling.

Main Control Room before the lights turned on
Checking a meter gauge with a flashlight in darkness•

Nuclear power – decay power

- A nuclear reactor will continue to produce heat in the megawatt range for months after shutdown

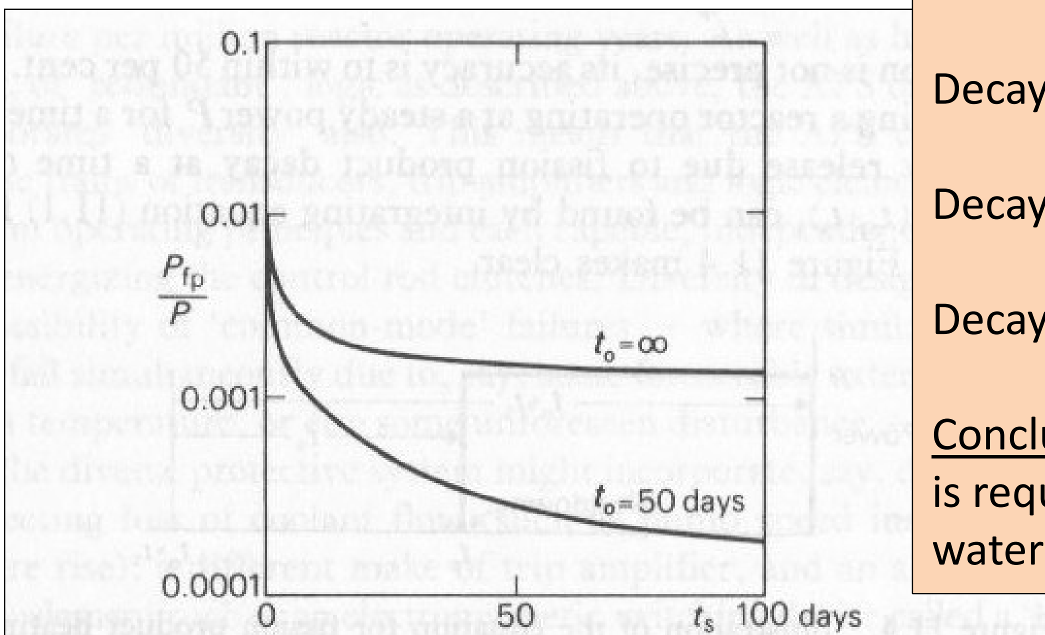


Figure 11.5. Fission product decay heating after shutdown

Typical large reactor power 3000 MW th.

Decay power after one minute c. 180 MW th.

Decay power after 1 day c. 10 MW th.

Decay power after 50 days c. 1000 kW th.

Conclusion: Very reliable decay heat removal is required (although the required flow of water is small).

Nuclear power – fuel cladding-water reactions

- Zirconium alloy is used to clad the fuel pins in water-cooled reactors because of its low neutron absorption.
- However, Zr reacts with steam at temperatures of about 1200 deg C (i.e. in loss of cooling accidents):

  $Zr + 2\ H_2O \rightarrow ZrO_2 + 2\ H_2$
- This can lead to loss of core integrity (meltdown), as at Three Mile Island and Fukushima.
- It also generates hydrogen gas.

After hydrogen explosions

Accident sequence – key events

	U1	U2	U3	U4	U5	U6
Plant state at earthquake, 14.36, 11th March	Operating	Operating	Operating	Outage, recently defuelled	Outage	Outage
ECCS declared to have failed	16.36, 11th March	16.36, 11th March	17.10, 13th March			
Containment venting started	10.17, 12th March	11.00, 13th March	08.41, 13th March			
H_2 explosion in reactor building	15.36, 12th March	-	11.01, 14th March	06.00, 15th March		
Seawater injection first started	08.20, 12th March	16.34, 14th March	11.55, 13th March			
H_2 explosion in containment	-	06.20, 15th March	-			
Damage to fuel pond integrity			By U3 H_2 explosion	By U3 H_2 explosion		
Water cannon aimed at fuel pond			17th March	20th March		
Reactor cooling by off-site supplies restored	3rd April	3rd April	3rd April			

Lessons learned – highlights

- Underestimation of tsunami risk in prior engineering risk assessments
- Inadequate engineering design (which allowed all safety systems to be made ineffective, and allowed the accident to escalate), including:
  - Failure of all diesels
  - Battery life only 8 hours
  - Complete failure of post-trip cooling
  - Lack of a hydrogen flaring/ignition system
- Poor accident response (either due to inadequate preparation or because accident response was impaired by the tsunami damage)
- Poor offsite communications, support and response

FUKUSHIMA - LESSONS LEARNED

KEY:-
WHITE – prior risk estimation
ORANGE – accident response
PALE BLUE – engineering design
RED – off-site response

Key lessons learned (from Japanese Government report, June 2011)

- Tsunami risk was under-estimated
- There was no 'last-ditch' source of cooling water.
- Accident management measures hadn't been thought through
- There should have been a hydrogen flaring/ignition system
- Emergency batteries had too small capacity
- Spent fuel cooling pond risk was underestimated
- Everything got flooded by the tsunami, so the cooling systems didn't work
- The response teams were having to cope with multiple nuclear accidents at Fukushima
- Failures of the contaminated ventilation systems impaired recovery operations
- The spent fuel ponds were located high up and were leaking contaminated water onto the recovery teams
- The main control room was temporarily made uninhabitable by rising radiation levels
- Communications, off-site support, and coordination were poor
- Monitoring dose uptake became difficult because the equipment was damaged by seawater
- Off-site infrastructure damage impeded accident response
- There was inadequate emergency training
- The instrumentation of the reactors and PCVs did not function
- The system for measuring radioactive discharges didn't work
- There has to be diversity as well as redundancy
- Strong safety culture is essential
- Lack of clear responsibilities for public safety and poor legal structures
- PSA is subject to uncertainty
- Policy on evacuation was changed during the accident

Jim Thomson, 2011
www.safetyinengineering.com

Lessons learned (continued)

- Poor offsite support and response can of course be explained by the difficulty of dealing with the nuclear accident during an immense civil emergency.
- **“The situation has become extremely trying for Japan, insofar as it has had to execute countermeasures for the nuclear accident whilst also dealing with the broader disaster caused by the earthquake and tsunamis.”**
- The concern about underestimation of risk has led to the European Union-wide review of nuclear plant external hazards – the so-called “stress tests”.

Fukushima Daiichi vs. Browns Ferry

The Tennessee Valley Authority (TVA) owns the Browns Ferry nuclear plant in Alabama, with three BWR units featuring Mark-1 type containments, similar to the Fukushima Daiichi plant design.

- TVA stated that the plants already had explosion-resistant pipes to vent hydrogen from the containment, fire hoses pre-placed to fill spent fuel pools in case of loss of cooling, and hardened diesel rooms, including 7-day supply of fuel, behind water-tight doors. The diesel switchgear is located within the reactor building, and thus is protected from flooding.
- As a result of Fukushima, TVA has bought diesel-driven fire pumps also.

Source: MIT-NSP-TR-025 Rev. 1, 26 July 2011

Japan announces new nuclear safety regulator

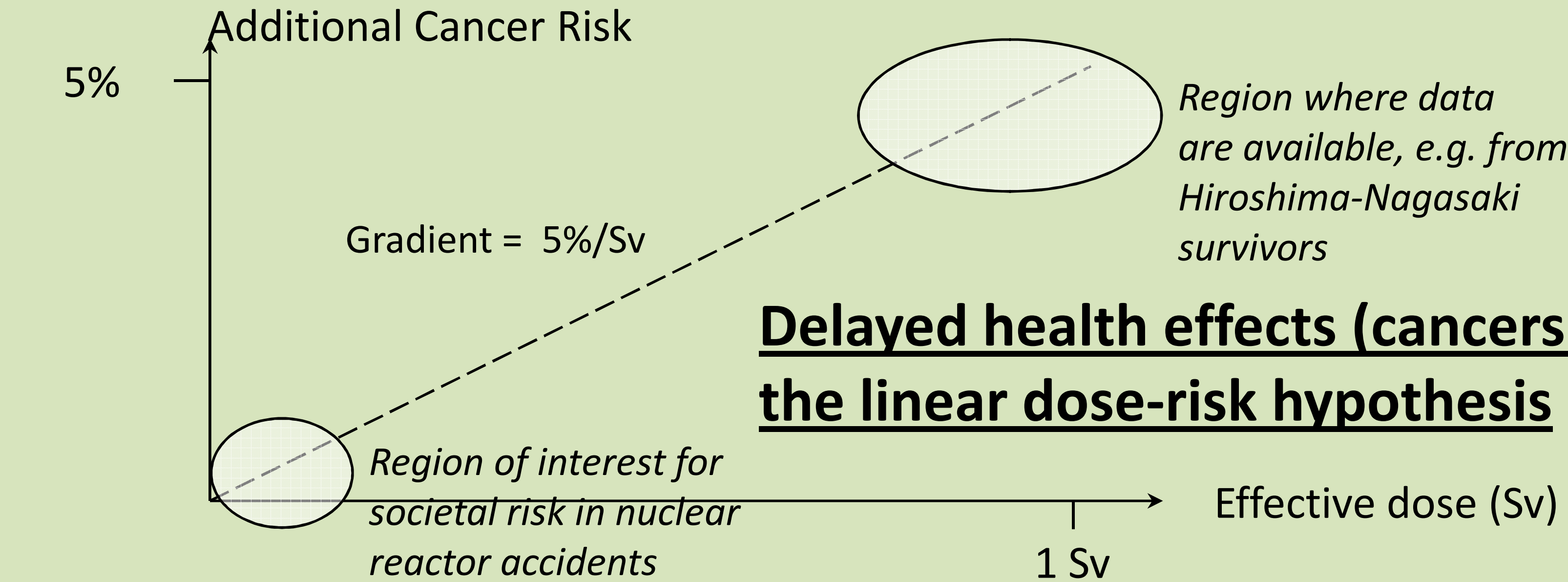
- Japan is to unveil plans for a new nuclear safety regulator which is expected to enforce tougher nuclear safety standards.
- Its Nuclear and Industrial Safety Agency (NISA) has been seen as a key factor in Japan's failure to prevent the Fukushima Daiichi nuclear crisis earlier this year.
- Japan's government plans to bring NISA under the Environment Agency and replace it with a new agency responsible for nuclear accident investigations, according to media reports.
- The Environment Ministry, while less powerful than the trade ministry which previously both regulated and promoted nuclear power, is seen as relatively untainted by the ties with industry which plagued the existing safety agency.

Source: various news reports, August 2011

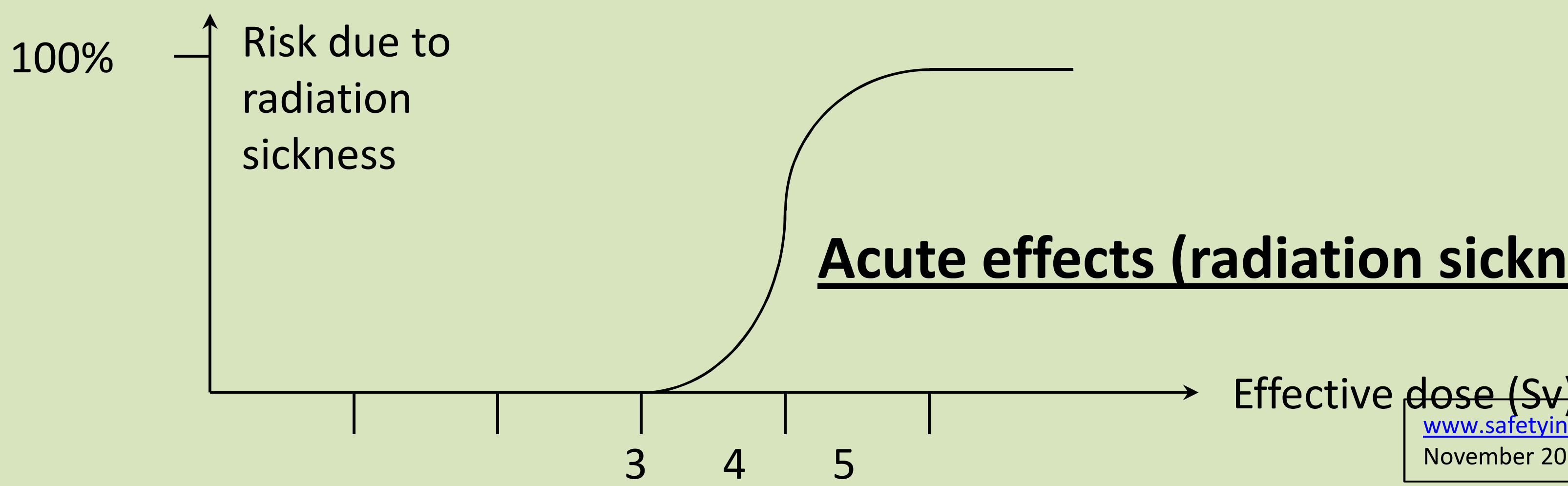
Radiation doses and radiological hazards

- *Other issue - Doserate effects - uncertain*
- *Normal cancer risk ~ 30%*

Delayed health effects (cancers) – the linear dose-risk hypothesis



Acute effects (radiation sickness)



Radiation doses and radiological hazards

- The Emergency Reference Level (ERL) = 300mSv effective dose
- Very small fractions of a reactor core's inventory would yield a major radiological hazard to the public if released off-site, e.g. typically a release of about one-millionth of the I-131 inventory in a reactor would equate to the Emergency Reference Level (ERL) for someone at the site boundary.

Isotopes	Characteristics
Iodine - 131	Volatile. Beta/gamma thyroid-seeker. Short half life (8d). Effects can be mitigated by swallowing iodate tablets.
Caesium - 137	Volatile. Permeates whole body (mimics sodium).
Actinides (e.g. Plutonium, Curium, Americium isotopes)	May be air-borne by fine particles of U_3O_8 in accidents. Alpha lung and bone seeker. Very long half lives.

Radiation doses and radiological hazards

4 different terms used:

DOSE is measured in Grays (Gy).
1 Gy = 1 Joule of radiation energy absorbed per kg of organ tissue

DOSE-EQUIVALENT is measured in Sieverts (Sv).
1 Sv = 1 Gy x *Relative Biological Effectiveness (RBE)*

where RBE =	1	for γ and β
	20	for α and neutrons, which are more intensely ionising.

EFFECTIVE DOSE EQUIVALENT(Sv) is used to equate single organ dose-equivalents to a whole-body dose-equivalent. Various coefficients are used for different body organs.
Effective dose is an analogue for individual risk.
The risk of early death from 1 Sv (Effective) is judged by ICRP to be 5%.

COLLECTIVE EFFECTIVE DOSE EQUIVALENT (man-Sv) is used to measure integrated population effective doses and hence societal risks.

Estimating health effects to the general population

- Deaths to the general public from radiation sickness have not yet arisen due to nuclear power accidents. The only real risk to the public is that of delayed health effects (cancers). Unfortunately, this is not very comforting for most.

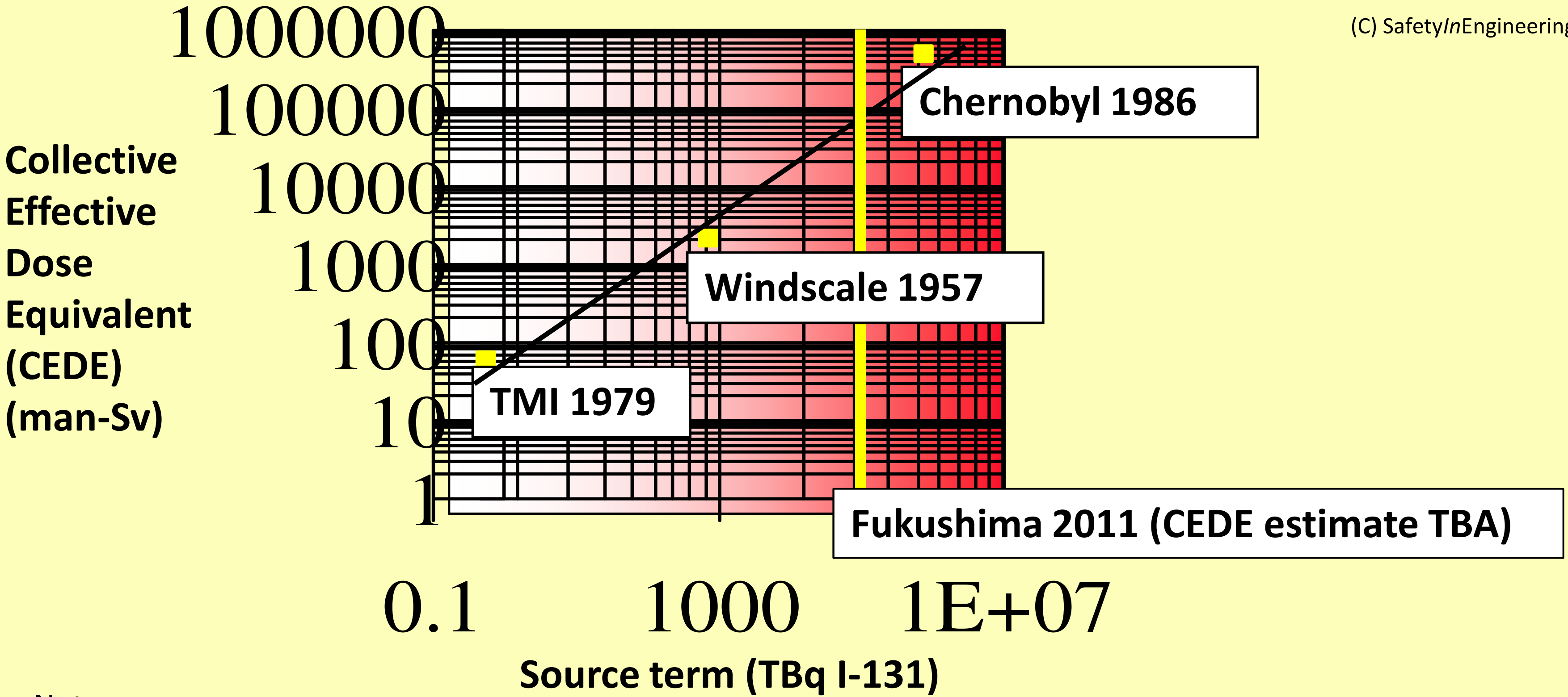
- The basis for estimating the risks of delayed health effects from radiation exposure is the linear dose-risk hypothesis . This is because:

  – Our knowledge of delayed health effects is largely based on studies of Hiroshima-Nagasaki survivors, most of whom received doses of several hundred milliSieverts or more.
  – It is difficult to know the extent of additional cancers caused by radiation when so many people contract cancer in any case (in excess of 30 per cent). (In engineering terms, the signal-to-noise ratio is high.) Hence it is impossible to know with confidence the effects of low-level radiation on cancer risk. Although many people have proposed theoretical models for this, the empirical data are absent because it is impossible to remove the background 'noise'.
  – However, in nuclear reactor accidents, exposures faced by the general population will only be of the order of a few milliSieverts or less.

- So, the linear dose-risk hypothesis is used to estimate risks from small doses in the absence of better information. The individual risks will represent small additions to the pre-existing 30 per cent or so 'normal' risk of acquiring cancer.

- However, in major nuclear accidents, when millions of people are exposed to small increases in their individual risk, the result of multiplying (very small theoretical individual risk) x (extremely large number of people) can be a large number. Furthermore, this calculated result is subject to great uncertainty, probably conservative, and completely unverifiable (because of the signal-to-noise ratio problem mentioned above).

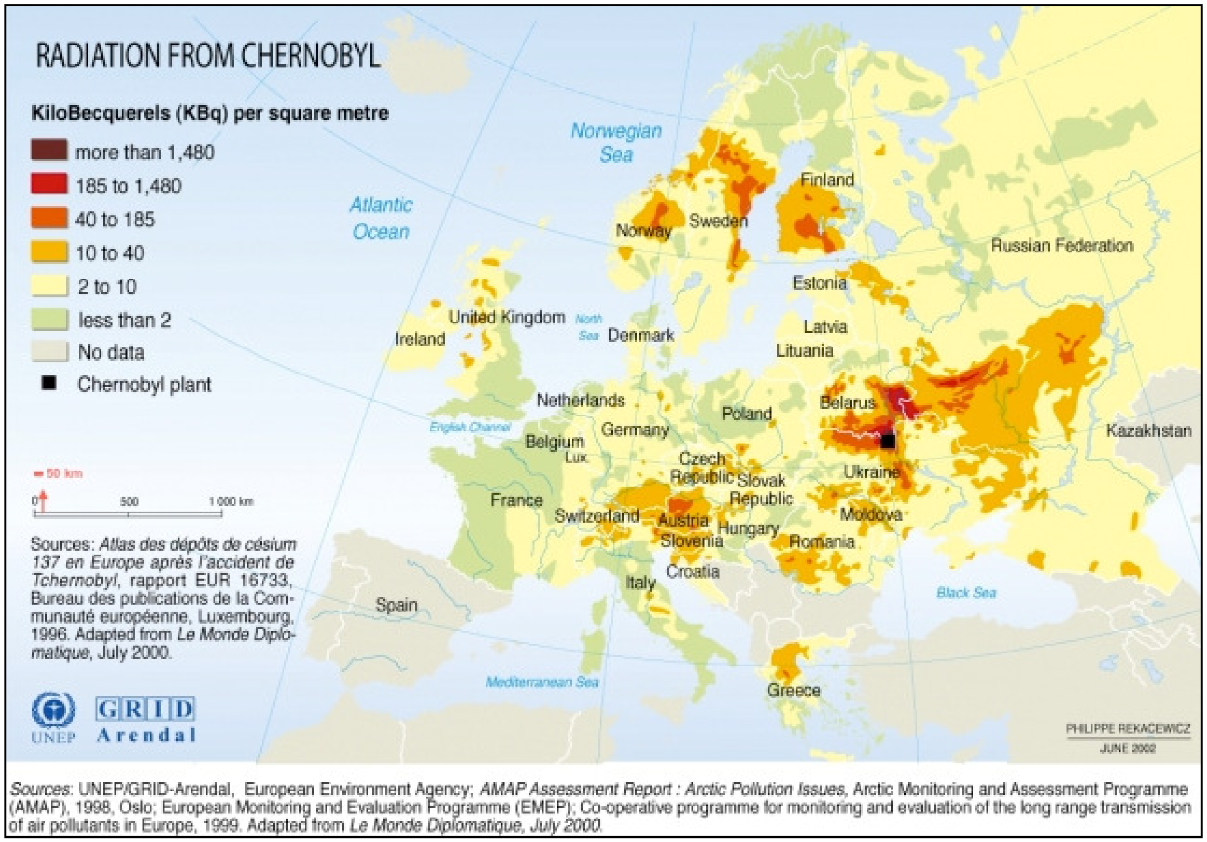
Consequences of reactor accidents – Fukushima update



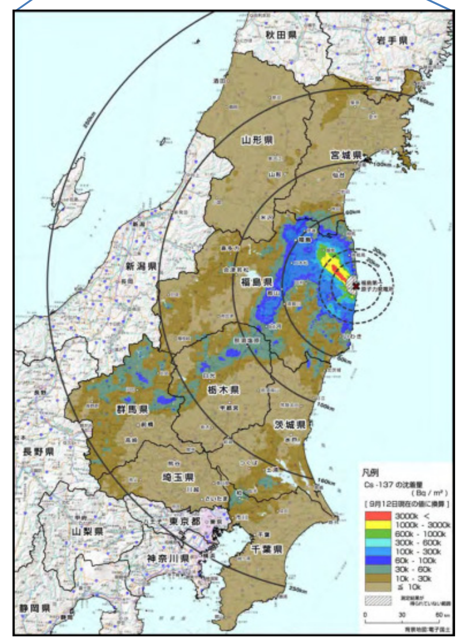
Notes:

1. The above graph uses I -131 as a surrogate measure of radiological release. Other isotopes (notably Cs and Pu) will also have been significant. I-131 is used for simplicity as a common single measure of the magnitude of radioactive release.
2. CEDE estimates are taken from the relevant recognised 'definitive' reports (Kemeny, NRPB, IAEA).
3. Using the ICRP risk coefficient of 5E-02/man-Sv leads to deduced cancer mortality estimates from the accidents as follows:
   - TMI c.1
   - Windscale c.100
   - Chernobyl c.10000
4. Airborne releases after the Fukushima accidents were estimated to be 1.5E+5 TBq I-131 by the Japanese Government in their June 2011 report. CEDE estimates are not yet available. Fukushima also led to significant water-borne releases.
5. If the empirical correlation for the first three major accidents (the straight line on the graph) holds true for Fukushima also, then the deduced long-term cancer mortalities for Fukushima are likely to be of the order of 1000.

Fukushima vs. Chernobyl – another view

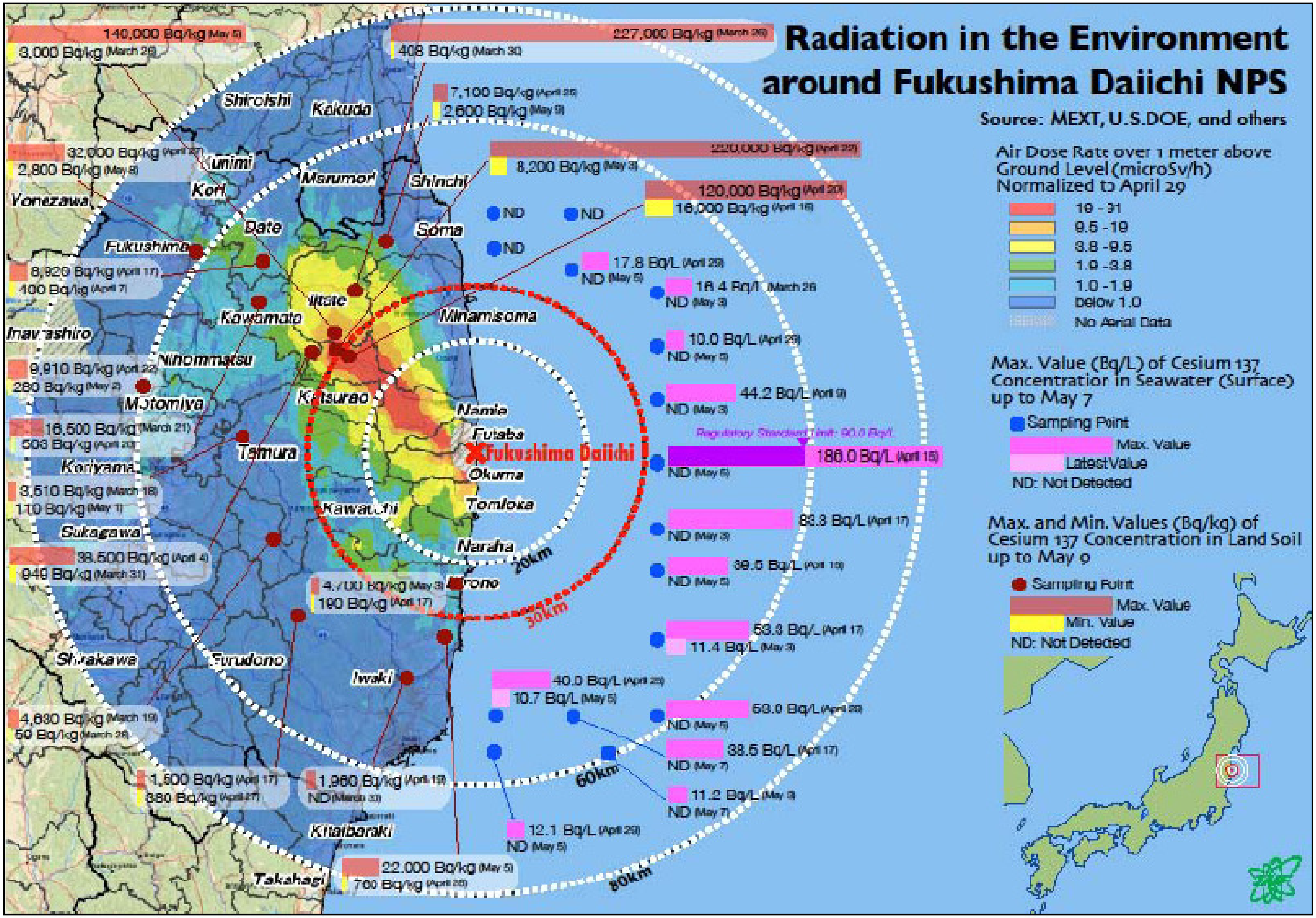


Japan to (approximately) the same scale as Europe.

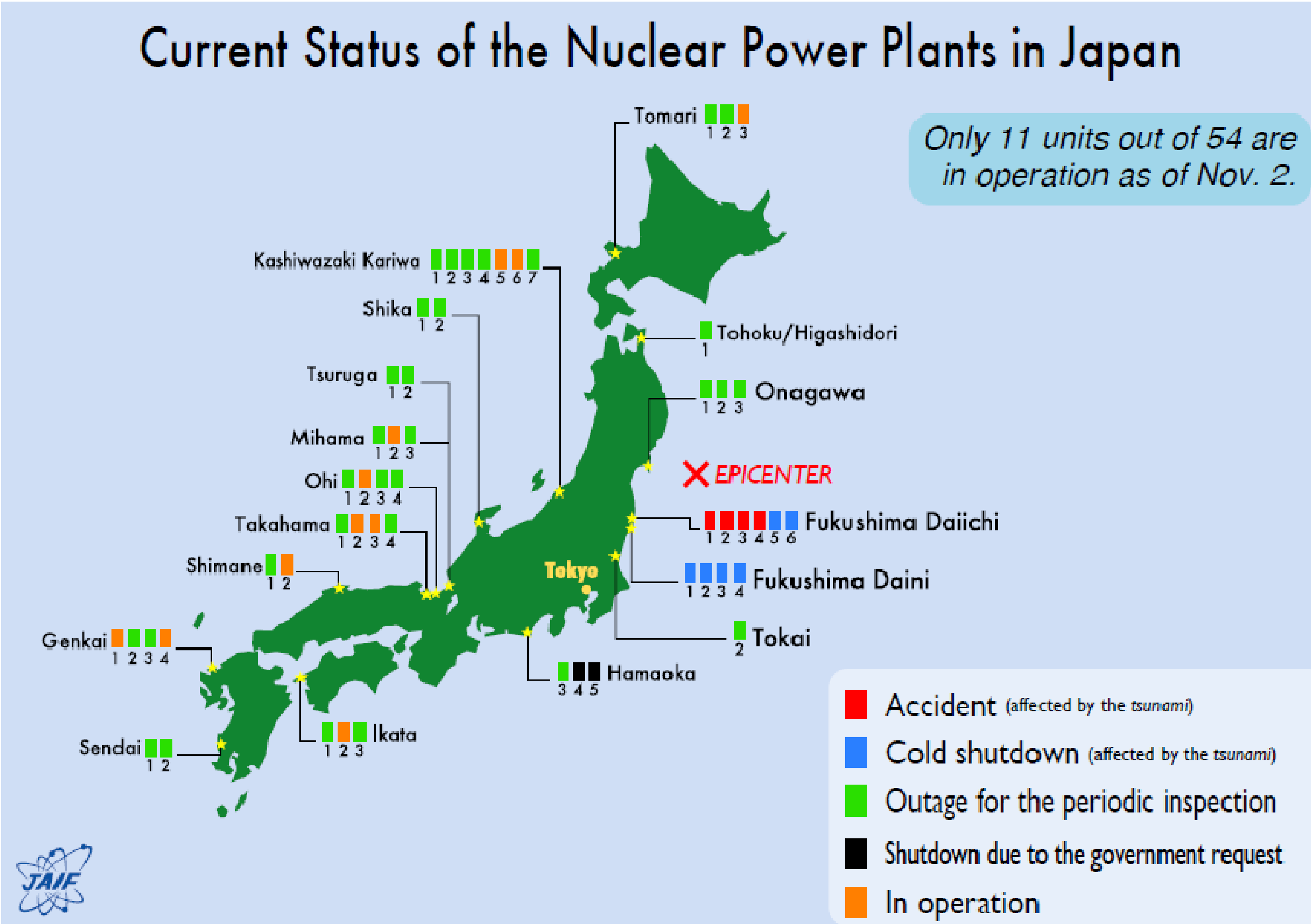


http://radioactivity.mext.go.jp/ja/1910/2011/09/1910_092917_1.pdf

(MEXT = Ministry of Education, Culture, Sports, Science & Technology)



Source: JAIF 17-11-11



Source: JAIF 17-11-11

Emergency planning: Nuclear emergencies during regional emergencies

Previous examples:

- Hunterston,

26-27th December 1998 storm (INES 2)

- Blayais (Gironde estuary),

extra-tropical cyclone,
storm surge/flood,
27th December 1999 (INES 2)

- Fort Calhoun, Nebraska,

Missouri river flood,
spring/summer 2011 (*photo*)

Washington Post

- Obviously none was as severe as Fukushima
- Emergency planning needs to address the likelihood that a nuclear emergency may occur at the same time as a regional emergency

Fort Calhoun, Nebraska, 16th June 2011

(Wikipedia) Flooding began to recede at the end of August.

Tsunami risk in the UK

Tsunami risk in the UK was reviewed in a DEFRA report of 2005. Tsunamis have occurred in the UK in the fairly recent past, in particular:

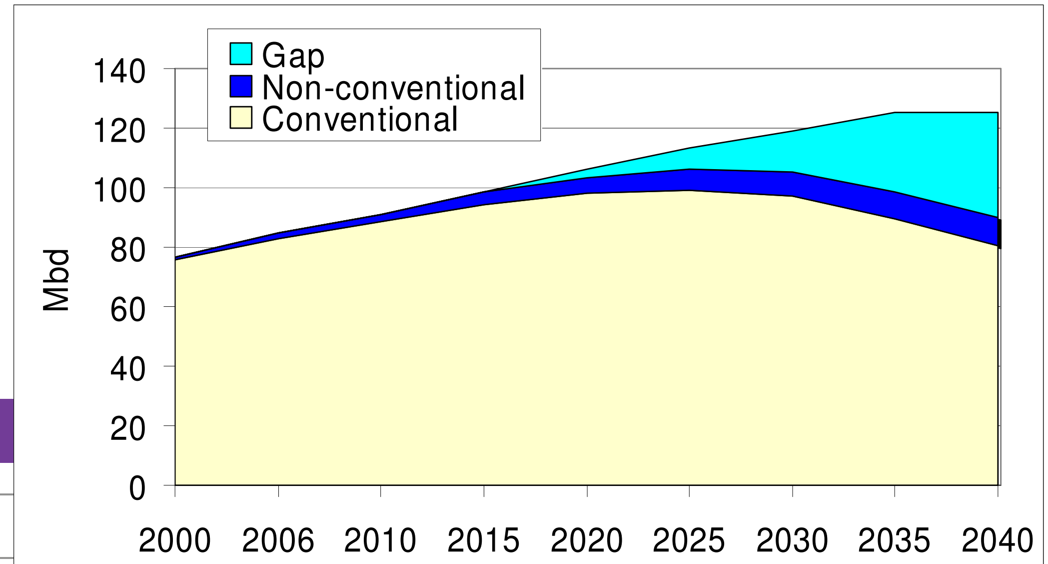
- The Storegga Slide event (a submarine landslide off the coast of Norway at about 64 degrees north) caused a tsunami in Britain about 7,250 years ago. This led to an 8 metre tsunami in Shetland, where the run-up was some 20 metres. Further south, the run-up was less; some 3-4 metres in northeast Scotland and about 1 metre in northeast England. The DEFRA report classifies such events as “probably the most significant tsunamis threats for the UK”.
- The most probable source of future tsunamis in the UK is an earthquake at the plate boundary off the southwest coast of Portugal. The great Lisbon earthquake of 1755 was probably about magnitude 8.5, and Lisbon itself was hit by a major tsunami where the wave heights were between 5 metres and 13 metres. The tsunami had significant effects in the Scilly Isles, Cornwall, Plymouth and South Wales. Its effects were also observed in the Caribbean and in Newfoundland.
- Concern has been expressed about possible “mega-tsunami” arising from landslides in the Canary Isles, and affecting the entire North Atlantic. The DEFRA report concludes that such events would be “likely to create tsunamis of only local concern”.

Indirect consequences of Fukushima:- delays to new nuclear build...........

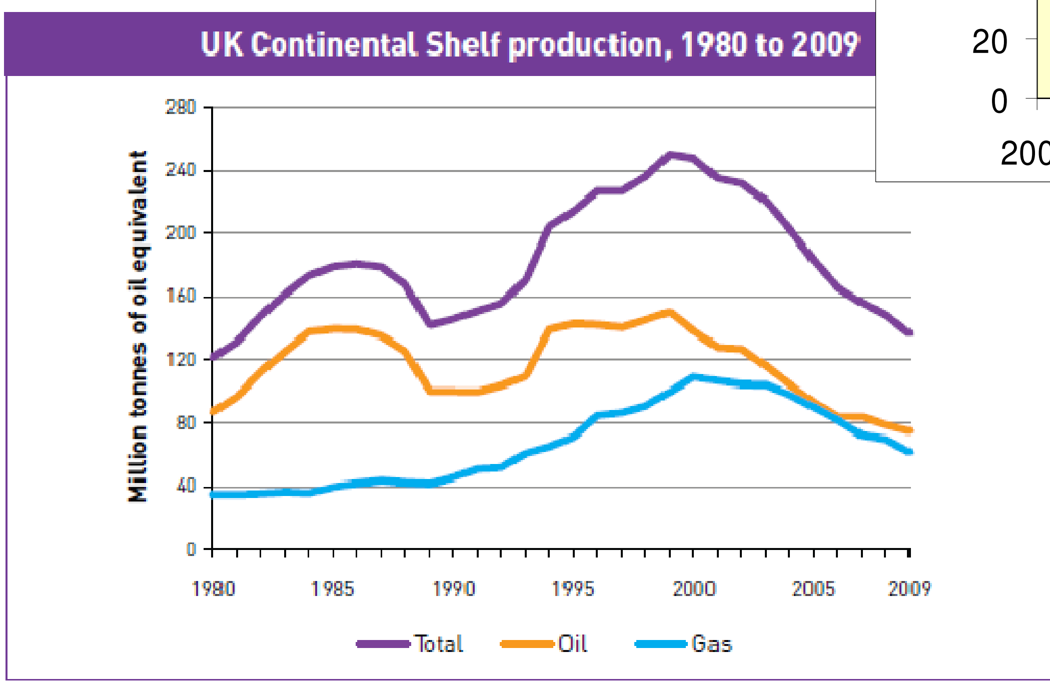
- In Europe, "stress tests" are being applied to existing plants to review their ability to withstand external hazards. This is right and proper.
- Germany has decided to shut down its existing nuclear plant by 2022. Although renewable energy is being promised, it is likely that much of the replacement power will come from imported coal-fired generation.
- Japan is suffering power shortages amidst delayed consents for its unaffected nuclear plants to re-start. There has been speculation that this will encourage major Japanese manufacturing companies to move abroad where stable power supplies can ensure reliable production. (This was getting likely in any case because of Japan's demographic problems due to its ageing population.)
- In the UK, there are some delays to the Generic Design Assessment process. It is difficult to be clear how much this will affect new build, but EdF has announced (July 2011) that there will in any case be delays and the first EPR in the UK is unlikely to generate power in 2018 as planned. Also in the UK, there may be a crisis of electricity supply in the latter part of this decade after old coal-fired plant is shutdown in 2015 and some older Advanced Gas-cooled Reactors shut down at around the same time.

......as the World approaches 'peak oil'......

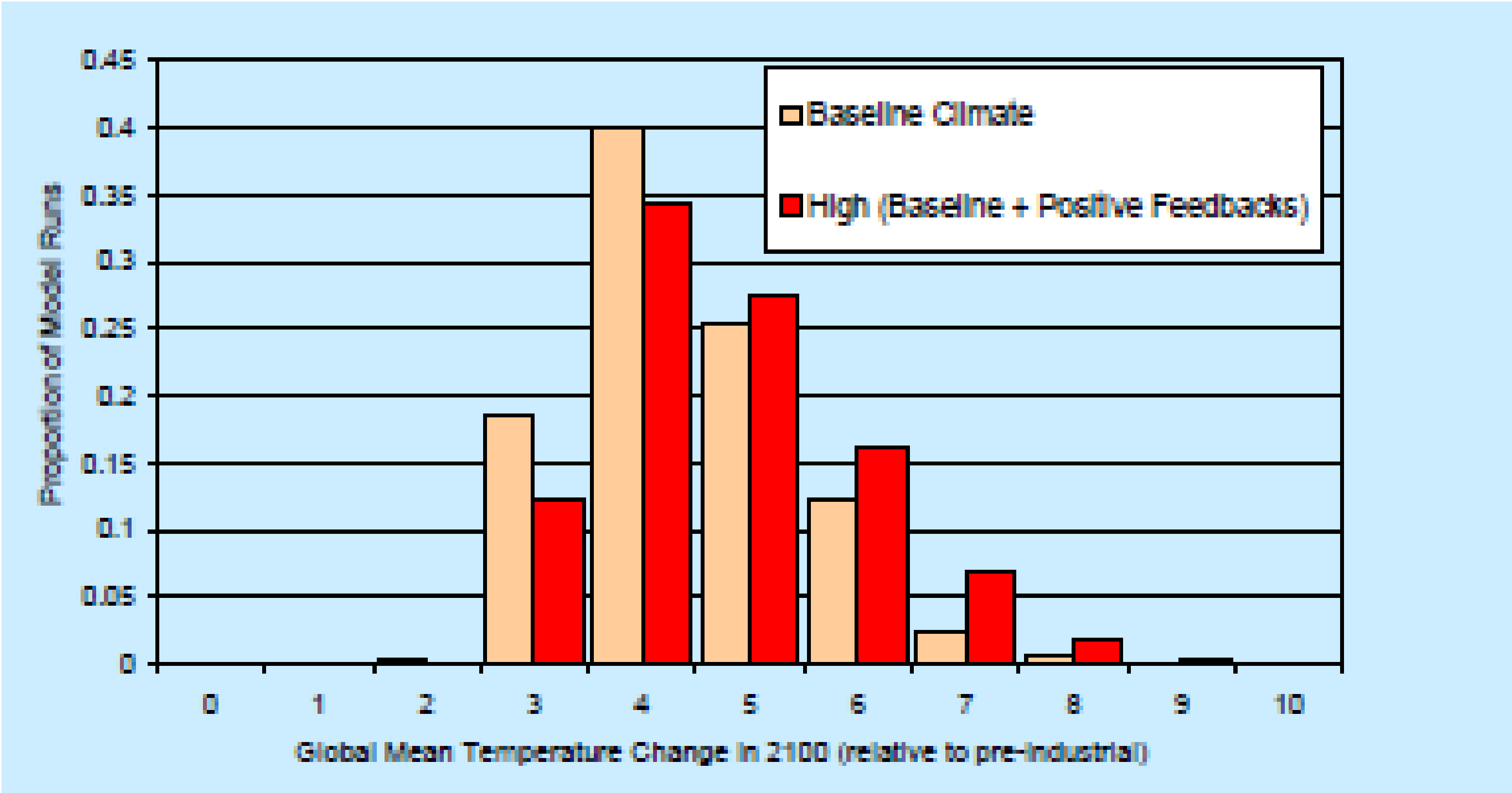
Supply/demand balance to 2040 in Medium Scenario



Source: DECC

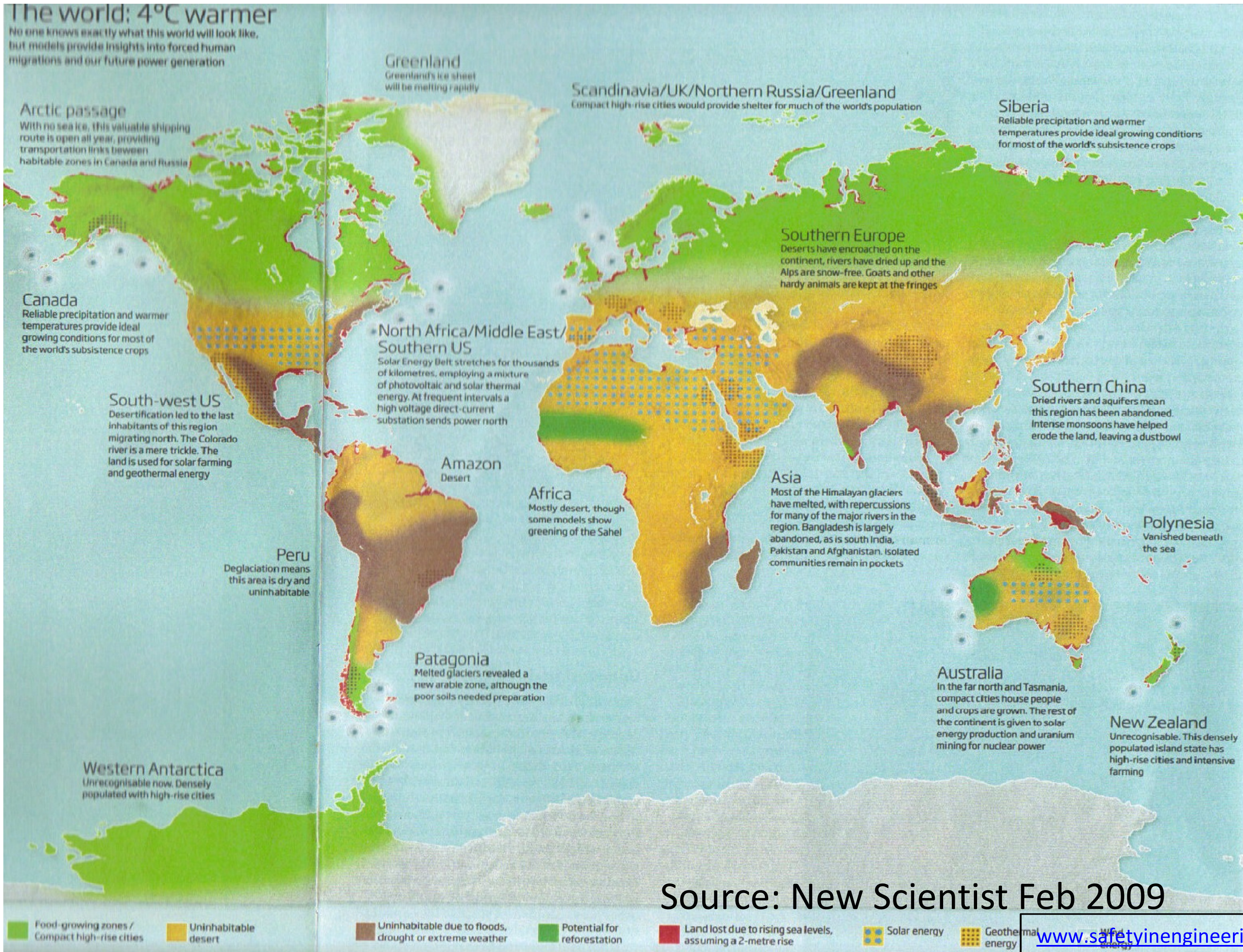


......and climate change approaches too......



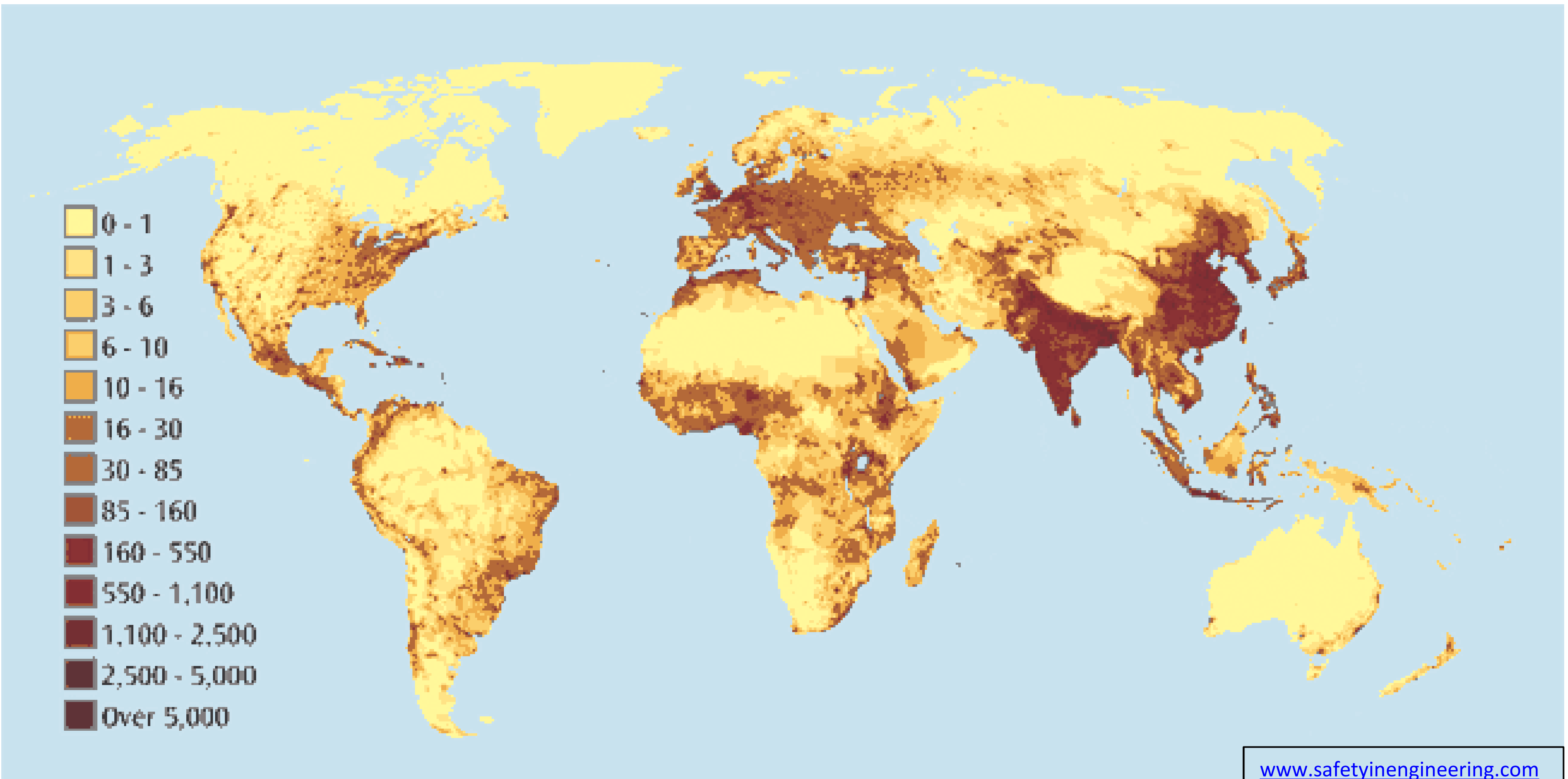
Source: Stern Report

The world 4 deg C warmer?



Source: New Scientist Feb 2009

.......compared with where people live in 2011......



Conclusions

- The earthquake and tsunami were an overwhelming (and ongoing) tragedy for Japan.
- The EU ‘stress tests’ are a good opportunity to review nuclear plant readiness against extreme external hazards.
- Nuclear safety cases perhaps need to go further in considering responses during extreme national emergencies.
- Peak oil is almost upon us and we need robust means of electricity generation that are not fossil fuel dependent. At the same time, there is a pressing need for greater use of nuclear and other non-GHG power technologies to deal with the very real threat of global warming.
- It would be a great shame for subsequent generations if excessive concerns about Fukushima led to significant delays in nuclear new build decisions.

Selected reports and web links

1. Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety - The Accident at TEPCO's Fukushima Nuclear Power Stations, June 2011 http://www.kantei.go.jp/foreign/kan/topics/201106/iaea_houkokusho_e.html
2. Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station , Institute of Nuclear Power Operations, INPO 11-005, November 2011 http://www.nei.org/resourcesandstats/documentlibrary/safetyandsecurity/reports/special-report-on-the-nuclear-accident-at-the-fukushima-daiichi-nuclear-power-station
3. Japan Atomic Industry Forum (JAIF) website, http://www.jaif.or.jp/english/
4. Review of Accident at Tokyo Electric Power Company Incorporated's Fukushima Daiichi Nuclear Power Station and Proposed Countermeasures (Draft), Japan Nuclear Technology Institute (JANTI), October, 2011 http://www.gengikyo.jp/english/
5. Tokyo Electric Power Company (TEPCO) website, http://www.tepco.co.jp/en/index-e.html
6. Monitoring information of environmental radioactivity level, Ministry of Education, Culture, Sports, Science and Technology (MEXT), http://radioactivity.mext.go.jp/en/
7. International Atomic Energy Agency website, www.iaea.org
8. EUROSAFE forum, Paris 7-8th November 2011 http://www.eurosafe-forum.org/eurosafe-forum-2011
9. Recommendations for Enhancing Reactor Safety in the 21st Century – the Near Term Task force Review of Insights from the Fukushima Dai-Ichi Accident, NRC, 12th July 2011, http://pbadupws.nrc.gov/docs/ML1118/ML111861807.pdf
8. Technical Lessons Learned from the Fukushima-Daichii Accident and Possible Corrective Actions for the Nuclear Industry: An Initial Evaluation, MIT-NSP-TR-025 May 2011, http://web.mit.edu/nse/pdf/news/2011/Fukushima_Lessons_Learned_MIT-NSP-025.pdf
10. The threat posed by tsunami to the UK, DEFRA, June 2005 http://archive.defra.gov.uk/environment/flooding/documents/risk/tsunami05.pdf
11. Japanese earthquake and tsunami: Implications for the UK nuclear industry , ONR, September 2011 http://www.hse.gov.uk/nuclear/fukushima/final-report.pdf