British Pugwash AGM – February 2012

Lessons of Fukushima

Mike Weightman

HM Chief Inspector of Nuclear Installations and Head of ONR

Office for Nuclear Regulation

An agency of HSE

Office for Nuclear Regulation (ONR)

- 1/4/11 ONR created as an agency of HSE prior to legislation to form as Statutory Corporation
- Safety (NII), Security (OCNS), Safeguards (UKSO), Transport (RMTT)
- NII >50 years old
- 450 staff, ~50% technical
- >95% costs recovered
- Joint Purpose: ‘Secure the protection of people and society from hazards’

ONR main activities

- Regulation through Programmes
  - Civil Nuclear Reactors, Sellafield, Other fuel cycle facilities, Defence, Civil Nuclear Security, Civil Nuclear and Radiological Material Transport
- Generic Design Assessment
- Policy, International, Research
- Goal setting regulatory regime – onus is on industry to demonstrate risks are adequately controlled

ONR Response to Fukushima

‘Securing the Protecting People and Society’

-17000 UK Nationals in Japan

- Setting up RCIS
- Advice to SAGE and COBR
- Links with International Stakeholders
- Prompt re-assurance of UK fleet
- Reports to SoS
- Stress Tests
- International Work

Office for Nuclear Regulation

An agency of HSE

Great East Japan Earthquake 11/3/11

- Magnitude 9 earthquake
- Subsequent tsunami
- ~20000 dead or missing
- Massive destruction
- Impaired infrastructure
- Affected all nuclear plants on the east coast
- Greatest consequences at Fukushima Dai-ichi

Nuclear Power Plants Affected

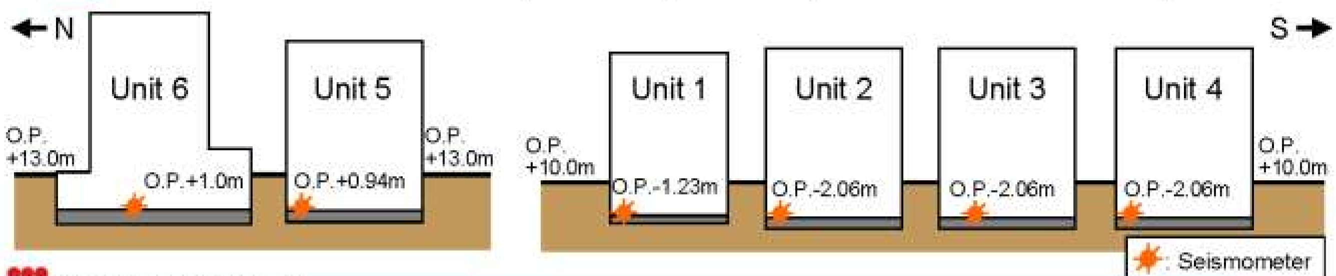
TEPCO Fukushima Dai-ichi Site

Fukushima Dai-ichi design basis

Records of Observations at Base-mat Slab of Reactor Building at Fukushima Daiichi NPS

	Maximum acceleration value from observation records (Gal)			Maximum response acceleration value (Gal)					Static horizontal acceleration (Gal)
				New design-basis seismic ground motion Ss			Original design-basis seismic ground motion		
	NS	EW	UD	NS	EW	UD	NS	EW	
Unit 1	460	447	258	487	489	412	245		470
Unit 2	348	$\boxed{550}$	302	441	438	420	250		
Unit 3	322	$\boxed{507}$	231	449	441	429	291	275	
Unit 4	281	319	200	447	445	422	291	283	
Unit 5	311	$\boxed{548}$	256	452	452	427	294	255	
Unit 6	298	444	244	445	448	415	495	500	

* $\boxed{}$ indicates the observed value was beyond the response of Ss, the others were under the response of Ss.



TOKYO ELECTRIC POWER COMPANY

Fukushima Dai-ichi - Earthquake

- Units 1-3 automatically shutdown in response to the earthquake
- Units 4-6 were already in outage
- The 12 (of 13 – one on maintenance) available Emergency Diesel Generators started up
- The earthquake caused the loss of all 6 off-site power lines

Power of the Tsunami (1) Dai-ichi – tsunami hitting the turbine buildings

Power of Tsunami (3) – 10 weeks after

Tsunami Inundation of the Site

Tsunami Inundation of the Site

Fukushima Dai-ichi – after tsunami

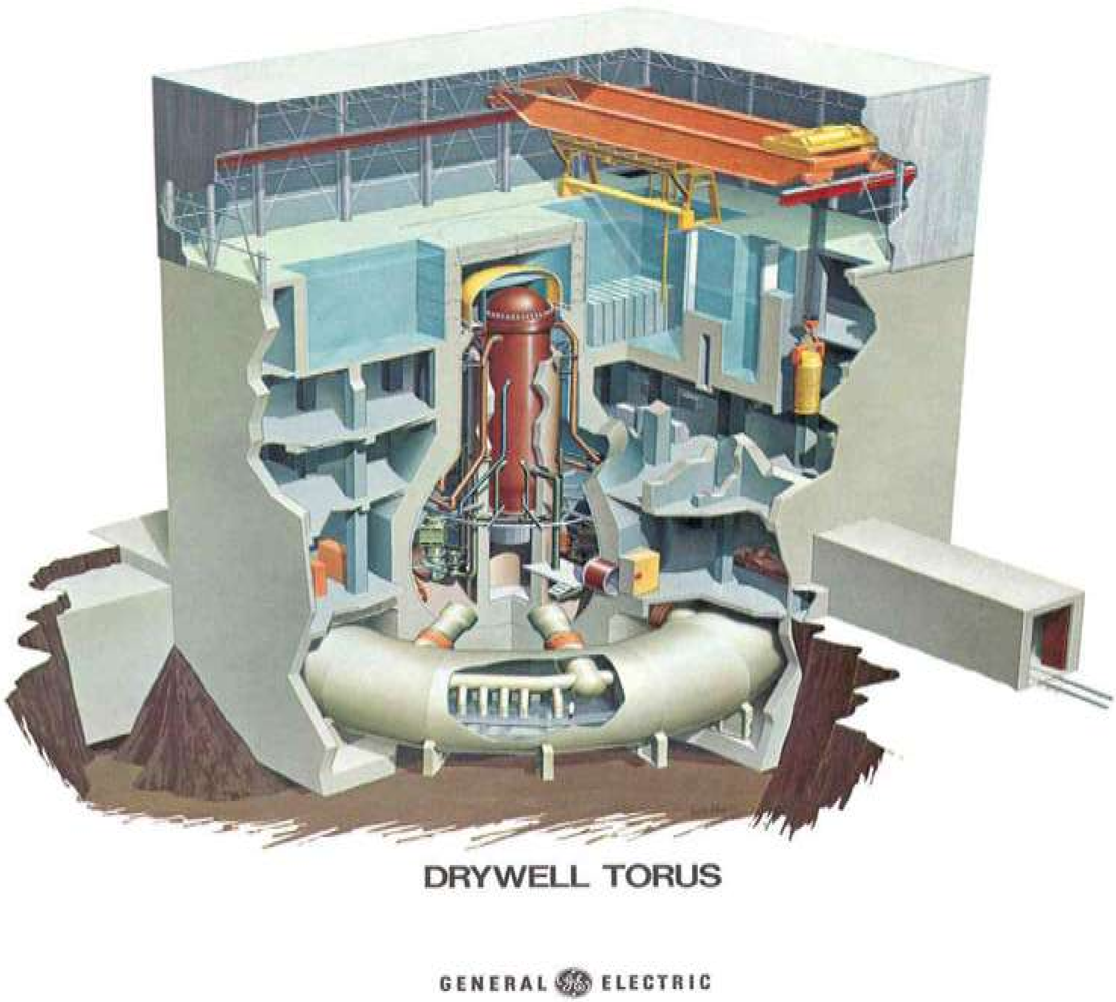
- Loss of all external power
- Only 1 of 13 EDGs available – Reactor 5 & 6
- Ultimate heat sink lost
- Unprecedented devastation
- Impaired infrastructure – little hope of short term help
- Long term developing scenario
- No AC power, little instrumentation, dark, access problems, 6 reactors etc, normal shift
- Attempts to use various means to provide cooling, operate valves, read instruments, etc

Before Earthquake & Tsunami

Before Explosion

Source: Nuclear and Industry Safety Agency(NISA), April 4, 2011, at IAEA http://www.nisa.meti.go.jp/english/files/en20110406-1-1.pdf

Schematic Cut-away of Mark I BWR



(figure courtesy of GE Hitachi Nuclear Energy)

Reactor Building 1 hydrogen explosion in upper area of building

- 11/3 14.47 Reactor trip, loss of off-site AC power
- 11/3 14.52 Isolation condenser started but operated intermittently
- 11/3 15.37 Loss of AC power and IC operated for about 3 hours after which lost normal means to inject water
- 8 hours after loss of IC some water injection via fire engine pump, venting and eventual need to use sea water
- 12/3 14.30 Vent primary containment
- 12/3 15.36 Explosion in top of reactor building
- Theoretical prediction: 11/3~17.00 Water level below top of fuel
- ….. Leading to zirconium reaction with water/steam, core damage

Source: NISA, April 2011, Government Report to IAEA

Reactor Building 2 – Explosion inside & release of steam

Fukushima Dai-ichi Unit 3 (indicative main events)

- 14/3 5.20 Vent primary containment
- 14/3 ~6.00 Explosion in top of reactor building

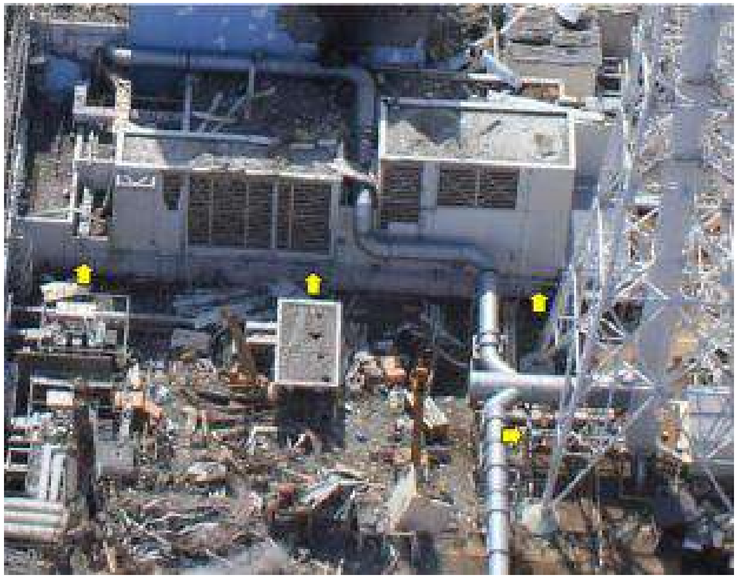
Reactor Building 3 & Impact on Reactor Building 4

Source: NISA, April 2011, Government Report to IAEA, June 2011

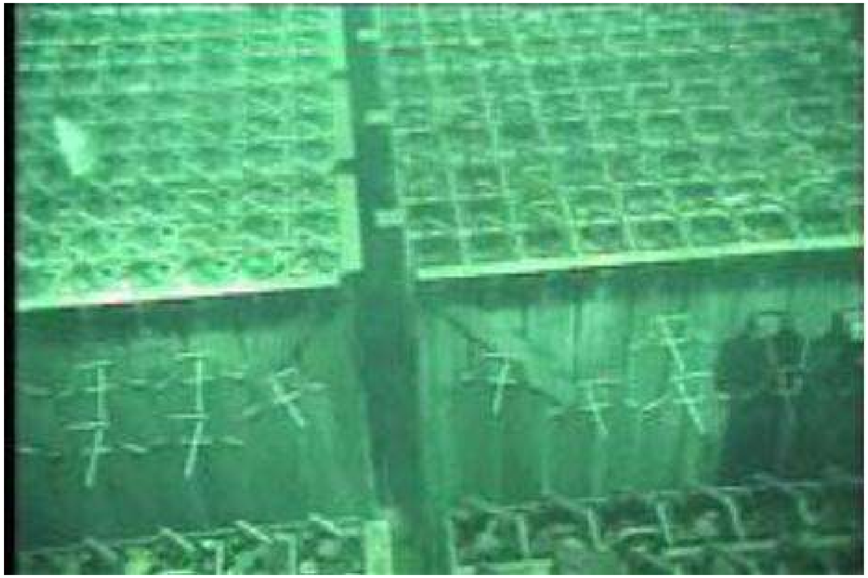
Fukushima Dai-ichi Unit 4 (defuelled)

- 11/3 15.38 loss of AC power
- 15/3 ~6.00 Explosion
- subsequent examination of fuel pond indicates not spent fuel reaction

Reactor Building 4 Explosion



Ventilation route RB3 to RB4



Fuel Racks in RB4 (under water)

Source: NISA, April 2011 in Government Report to IAEA, June 2011

Cooling of the Fuel Pond for Reactor Building 4

Fukushima Dai-ichi Units 5 & 6 (outage)

- 11/3 14.46 Plant trip, loss of off-site AC power
- 11/3 15.41 Loss of AC power but work to utilise one available diesel for both reactors
- 20/3 14.30 Unit 5 cold shutdown
- 20/3 19.27 Unit 6 cold shutdown

Fukushima Dai-ichi

Design/Regulatory basis for earthquake more or less robust

But…

- Design/Regulatory basis for associated tsunami inadequate – 3.1m cf 14-15m
- Plant layout appears to be optimised for earthquake without consideration of associated flooding:
  - Emergency diesels & electrical switchgear located in lower areas such as turbine hall basements
- Lack of consideration of common mode vulnerabilities
  - Extensive use of water cooled diesels
  - Ultimate heat sink arrangements
  - Off site infrastructure
  - Staffing arrangements
  - Instrumentation, communications, sources of power to valves
- Severe Accident response arrangements could not cope

Fukushima Dai-ichi

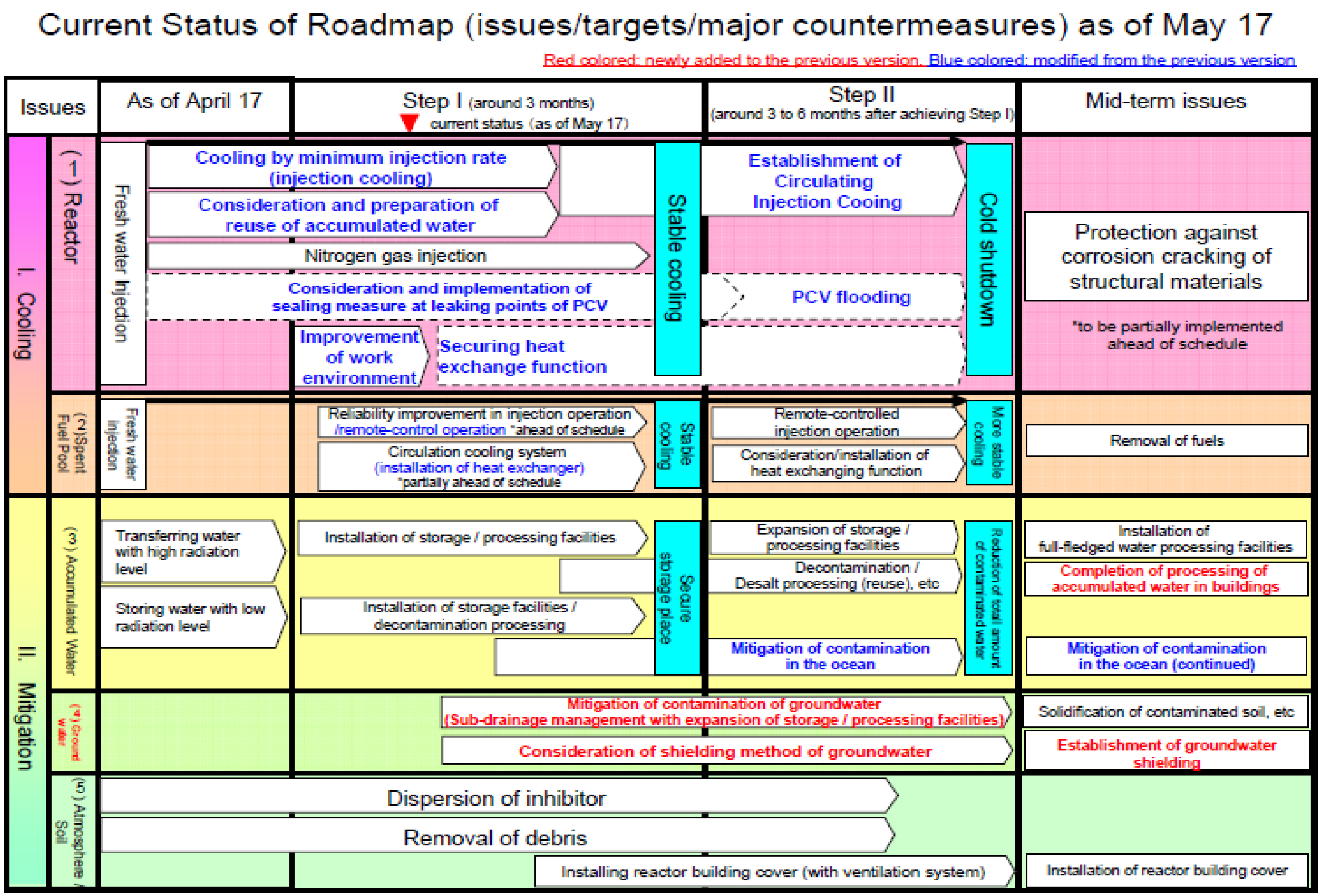
- Regulatory Design Basis tsunami of 3.1m, TEPCO 5.7m

Japanese Safety Regulation for Severe Accidents

- The Regulatory Guide for Reviewing Safety Design *does not take total AC power loss as a design basis event*.
  - *No particular considerations are necessary against a* ***long-term*** *total AC power loss*
  - the assumption of a total AC power loss is not necessary if the emergency AC power system is reliable enough
  - Loss of all seawater cooling system functions is not taken as a design basis event.
- Flammability Control System (FCS) is not aimed at preventing hydrogen combustion *inside the reactor building*
- In Japan, a civil standard on seismic PSA is also established, *while study of PSA related to other external events such as flooding has only started.*
- (Based on NSC decision in 1992).. licensees have taken *voluntary actions (not included in regulatory requirements),* such as measures to prevent accidents from becoming severe accidents

Source: Dr Tatsujiro Suzuki, 59th Pugwash Conference, July 2011

TEPCO Road Map for Stabilisation



Source: http://www.meti.go.jp/english/earthquake/nuclear/roadmap/pdf/110517TEPCO_status2.pdf

Office for Nuclear Regulation

An agency of HSE

Impact of the TEPCO Fukushima Dai-ichi Nuclear Accident

Size of Fukushima Nuclear Accident – INES level 7, roughly 1/5~1/10 of Chernobyl

	Assumed amount of the discharge from Fukushima Dai-ichi NPS		(Reference) Amount of the discharge from the Chernobyl accident
	Estimated by NISA	Announced by NSC	
^{131}I … (a)	1.3×10^{17} Bq	1.5×10^{17} Bq	1.8×10^{18} Bq
^{137}Cs	6.1×10^{15} Bq	1.2×10^{16} Bq	8.5×10^{16} Bq
(Converted value to ^{131}I) … (b)	2.4×10^{17} Bq	4.8×10^{17} Bq	3.4×10^{18} Bq
(a) + (b)	3.7×10^{17} Bq	6.3×10^{17} Bq	5.2×10^{18} Bq

Source: NISA, April 12, 2011

Contaminated water discharge to the sea

Discharge amount of the stagnant water with low-level radioactivity, etc. from the Fukushima Dai-ichi NPS

< Table 1 >

	Radioactive Concentration (Bq/cm^3)				Discharge Amount (m^3)	Periods of Discharge
	I-131	Cs-134	Cs-137	sum		
Stagnant water in the Radioactive Waste Treatment Facilities	6.3E+00	4.4E+00	4.4E+00	1.5E+01	9,070	4/4 19:03 – 4/6 6:30 4/6 18:00 – 4/8 22:20 4/8 23:45 – 4/10 17:40
Water in the Sub Drain Pit of the Unit 5	1.6E+00	2.5E-01	2.7E-01	2.1E+00	950	4/5 17:20 – 4/8 12:14
Water in the Sub Drain Pit of the Unit 6	2.0E+01	4.7E+00	4.9E+00	3.0E+01	373	4/4 21:00 – 4/9 18:52

※Radioactive Concentration (Bq/cm3) of the stagnant water in the Radioactive Waste Treatment Facilities is assessed by the maximum value of the samples in the two Facilities shown in the following table.

	Radioactive Concentration (Bq/cm3)			
	I-131	Cs-134	Cs-137	Sum
Stagnant water in the Radioactive Waste Treatment Facilities (In the Non-Controlled	6.3E+00	2.7E+00	2.8E+00	1.2E+01
Stagnant water in the Radioactive Waste Treatment Facilities (In the Controlled Area)	8.7E-01	4.4E+00	4.4E+00	9.7E+00

Office for Nuclear Regulation

An agency of HSE

Source: NISA Apil 15, 2011

Containing & Treating 100,000+ tons of contaminated water

http://www.tepco.co.jp/tepconews/pressroom/110311/index-j.html

People

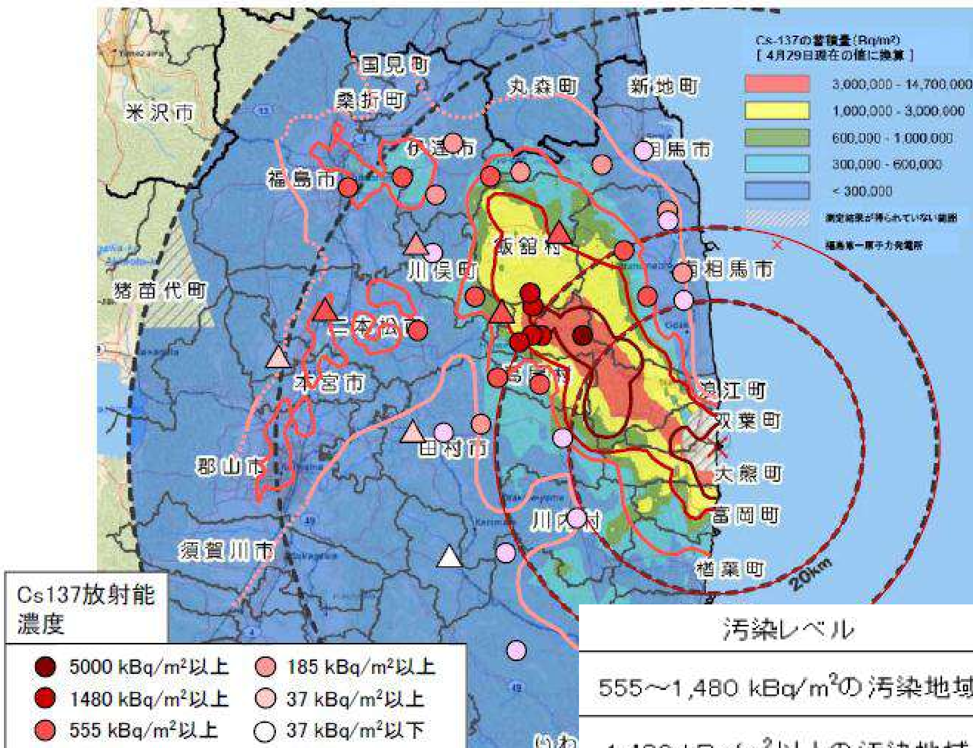
- Workers at plant – average dose is less than 10 mSv, some more than 250 mSv but none with long lasting acute effects

- Public
  - maximum may be less than 20mSV with social dose from some estimates leading to 0.1%* increase in cancer rates, and very much less stochastic deaths than from acute deaths from direct effects of tsunami
  - but fear of ionising radiation and health impact of evacuation likely to be biggest effect (over 100,000 people evacuated in 20km zone, over 340,000 refugees in total)

*Source: Frank N. von Hippel (September/October 2011 vol. 67 no. 5). Bulletin of the Atomic Scientists. pp. 27–36.

Land Contamination

5月6日公表文科省・米国DOE航空機モニタリング結果との重ね合わせ



汚染レベル	Fukushima 今回の事故(注)	Chernobyl チェルノブイリ事故
555〜1,480 kBq/m^{2}の汚染地域	約 700 km^2	約 7,200 km^2
1,480 kBq/m^{2}以上の汚染地域	約 600 km^2	約 3,100 km^2

Office for Nuclear Regulation

An agency of HSE

Source: T. Kawada, “Current Status of Soil Contamination and how to respond ,” Presentation at Japan Atomic Energy Commission Meeting, May 24, 2011

Social Impact

- Loss of electricity supply
  - TEPCO supplies power to 29m people
  - Could be only 3* out of 54 nuclear reactors in Japan operating
  - Struggling to convince public to restart reactors after outage and "stress testing"
- Evacuees and loss of use of land
- Remediation of land

*At time of writing

Political Impact

- Japanese government:
  - Contribution to PM resigning
  - Possible change of energy policy

- Other government's decisions to phase out nuclear power or not develop it, nuclear power area of difference in French Presidential Election

Economic Impact

- Reports that TEPCO faces damage claims of at least $60B
- Nikki Stock market dropped 5% after earthquake and another 11% after nuclear accident
- Loss of production of Japanese industry both domestic and as a global supplier

Impacts Dependency?

- Not so much on “hard science”
- More on:
  - Social Trust, Confidence, Beliefs and Perceptions
  - Political Requirements
- Some, e.g. remediation of land and return of evacuees, depend on mixture of both

Lessons to be Learnt

Chief Inspector Interim Report – published mid May

- Focus on UK Civil Nuclear Power Plants (NPP)
- Background to radiation, technology and regulation
- Timeline of events
- Comparison of Japan situation and UK
- Developed by ONR specialists through submissions
  - Independent Technical Advisory Panel
- 11 Conclusions, 26 Recommendations

Interim Report Recommendations

- General
- Relevant to the Regulator
- Relevant to the Nuclear Industry
- Way Forward

General Recommendations

- Improve dissemination of information
- Identify lessons for contingency planning
- Review UK nuclear emergency arrangements
- Enhance Openness and Transparency

Office for Nuclear Regulation

An agency of HSE

Recommendations for the Regulator

- Review detailed SAPS
- Consider exercising long term accidents
- Review ONRs response
- Accelerate moves to more openness and transparency

Recommendations for Industry

- Review site dependency - enhance self sufficiency
- Compare difference of consequences at Fukushima Dai-ichi and Dai-ni
- Review flooding studies
- Ensure adequate safety cases for new sites of multi reactors

Recommendations for Industry

- Ensure adequacy of spent fuel management strategies

- Review plant layout
- Ensure adequacy of the design of new spent fuel ponds
- Consider detailed information regarding performance of concrete and other structures

Recommendations for Industry

- Consider the impact of the robustness of the UK grid in severe conditions
- Review the need for long term diverse supplies
- Review contingency plans for pond water make up
- Review venting routes
- Review provision of control
- Review communications

Recommendations for Industry

- Review and extend accident analysis sequences

Office for Nuclear Regulation

An agency of HSE

Recommendations way forward

- Respond to the recommendations within one month

Chief Inspector Final Report published October

- Inclusion of all UK Nuclear Facilities
- Built on Interim Report
- Additional information considered by ONR specialists (IAEA mission, substantial Japanese report, responses to Interim Report, more submissions)
- 6 additional conclusions and 12 additional recommendations

KEY MESSAGES from HMCI Reports

- Confident no fundamental weakness in UK nuclear facilities or systems

- No matter how high the standards, the quest for improvement must never stop

- Vital to learn lessons and take action

- Underlying it all is a need for a vibrant and active safety culture

IAEA Fact Finding mission

- IAEA and Government of Japan agreement
- 24 May 2011 to 1 June 2011
- Open provision of information
- Team of world experts
- Ministerial meetings
- Visit 3 sites
- 16 lessons, 15 Conclusions
- Summary Report to Japanese
- 140 page Report to IAEA

Summary of the Final Report by the IAEA Fact Finding Team (06/16/11) 16 Lessons

Lesson 1: There is a need to ensure that in considering external natural hazards:

- common cause failure should be particularly considered for multiple unit sites and multiple sites, and for independent unit recovery options, utilizing all on-site resources should be provided;

Lesson 8: The risk and implications of hydrogen explosions should be revisited and necessary mitigating systems should be implemented.

Lesson 9: Particularly in relation to preventing loss of safety functionality, the robustness of defence-in-depth against common cause failure should be based on providing adequate diversity (as well as redundancy and physical separation) for essential safety functions.

Lesson 16: Nuclear regulatory systems should ensure that regulatory independence and clarity of roles are preserved in all circumstances in line with IAEA Safety Standards.

Source: IAEA International Fact Finding Expert Mission of the Nuclear Accident Following the Great East Japan Earthquake and Tsunami, 16 June, 2011.

Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety (06/07/2011)

5 Categories of 28 list of Lessons learned

1. Strengthen preventive measures against a severe accident
2. Enhancement of Responsive measures against a severe accident
3. Emergency responses to nuclear disaster accident
4. Robustness of the safety infrastructure established at the nuclear power station
5. Thoroughness in safety culture while summing up all the lessons.

Source: Nuclear Emergency Response Headquarters, Government of Japan, “”Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety

-The Accident at TEPCO’s Fukushima Nuclear Power Stations -”, June 2011.

Peer Review

- EC Peer Review of all National Reports

- Ensure lessons are learned

EC Stress Test Specification

- Initiating Events
  - – Extreme natural hazards

- Loss of Safety Systems
  - – Cooling and Power
- Severe Accident Management

UK Stress Test – Request to non-NPP

- ONR requested all UK nuclear installations undertake the ‘stress test’

- All installations have reported

- ‘non-NPP’ National Report due Spring 2012

Openness

- All ONR reports on our website
- All licensee reports redacted and published on their websites
- All submissions from all stakeholders published on our website (together with how ONR have considered and sentenced every one)

IAEA Ministerial Conference

- IAEA Ministerial Conference regarding Fukushima accident
- 3 working sessions
- Fukushima lessons
- Emergency Response
- Global framework
- Action plan being developed

IAEA Director General's Concluding Remarks (24.06.11) 5 Agreed points

- Strengthen IAEA Safety Standards;
- Systematically review the safety of all nuclear power plants, including by expanding the IAEA's programme of expert peer reviews;
- Enhance the effectiveness of national nuclear regulatory bodies and ensure their independence;
- Strengthen the global emergency preparedness and response system; and
- Expand the Agency's role in receiving and disseminating information.

Summary of Impacts of Fukushima Dai-ichi Nuclear Accident

Japan

- Radiological impact on people
- Radiological impact on sea and land
- Social Impact
- Political Impact
- Economic Impact

Global

- Nuclear Power development
- Global economy

Summary of Lessons

- Get the design basis right but prepare for severe accidents & periodically review
- Clarity of Roles/Responsibilities of Government, Independent Regulator, Operators
- Cultural Shift in industry
  - Transparency and Openness
  - Continuous Improvement Challenge

Summary of Lessons

But, are the lessons/questions:

Was it an institutional and cultural failing rather than a failure of science, engineering or people?

and

Are the hazards and consequences of nuclear power more about the potential social, political and economic impact than harm to people?

ONR's purpose stays the same:

To secure the protection of people and society

From the hazards of the nuclear industry

On sites and during transport