# Fukushima-1 Accident: Could It Happen Here?

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# Fukushima-1 Accident: Could It Happen Here*?

- Basic facts on natural disasters and nuclear power
- Accident at Fukushima Dai-ichi site
- Health effects of radiation release
- Regulatory safety issues for the U.S.
- Accident cleanup and waste management
- Risk communication and future of nuclear

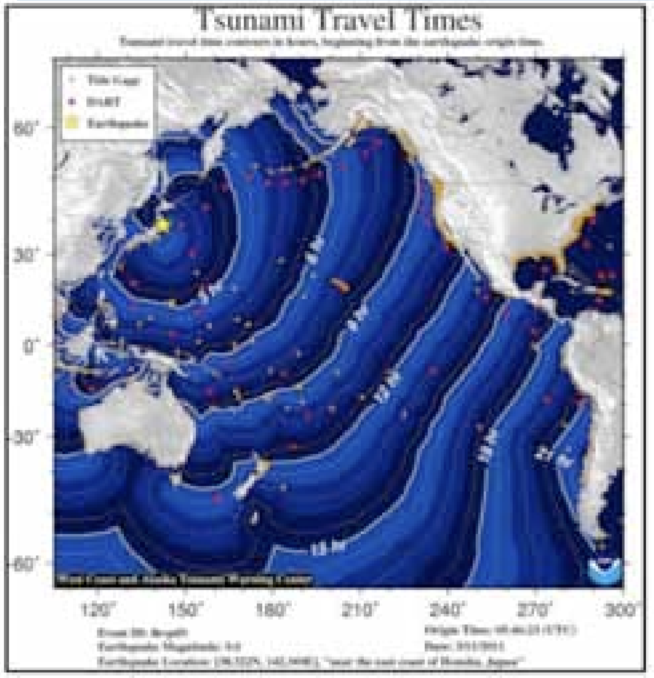
* Info: TEPCO, NISA, MEXT

# Basic facts on natural disasters and nuclear power

- How did the earthquake and tsunami compare to the design basis? What about natural disasters in the U.S.
- Describe the design philosophy for natural disasters.
- Describe the current nuclear power position in Japan
- Describe the BWR system and associated safety systems
- What is the regulatory structure in Japan and how is it different that other nations such as France and the U.S.?

# The Event

- The Fukushima nuclear facilities were damaged in a magnitude 9 earthquake on March 11 (2.46pm Japan time), centered offshore of the Sendai region (Tokyo is about 250km southwest).
  - Plant designed for magnitude 8.2 earthquake. A 9 magnitude quake is much greater in size.
- Serious secondary effects followed including a significantly large tsunami (>factor of 3), significant aftershocks and fires at many industrial facilities.
- Over 18,000 dead, 8,000 missing, 150,000 homeless little potable water, food, electricity over 1000sq.mi.

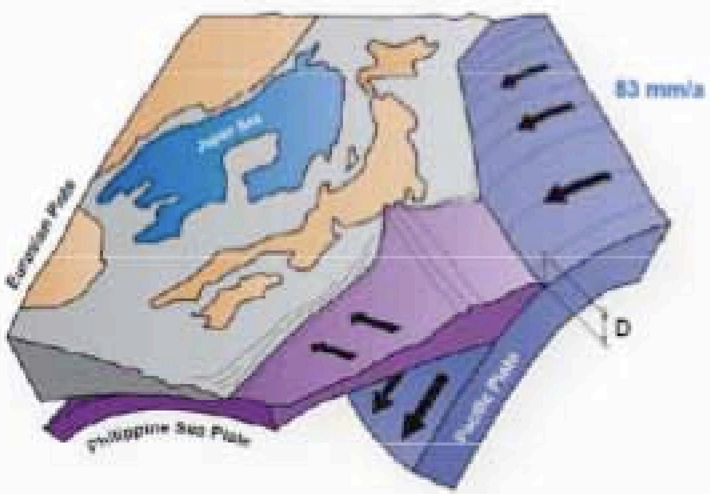
# Describe design philosophy for natural disasters

- All civil infrastructures are designed against natural disasters
- Nuclear power plants in the U.S. are designed to safely shutdown without incident based on historical disasters
  - Largest event in the region (earthquake, tornado, flood, hurricane)
  - Recent large U.S. natural disasters have not resulted in plant damage
  - Katrina, Southern tornadoes, Midwest floods were devastating in loss of life/property and in all cases the nuclear plants safely shutdown
- Japanese philosophy is similar but not the exactly the same (apparently the earthquake and tsunami were disconnected)

# Tsunami was historically large and 'unforseen'

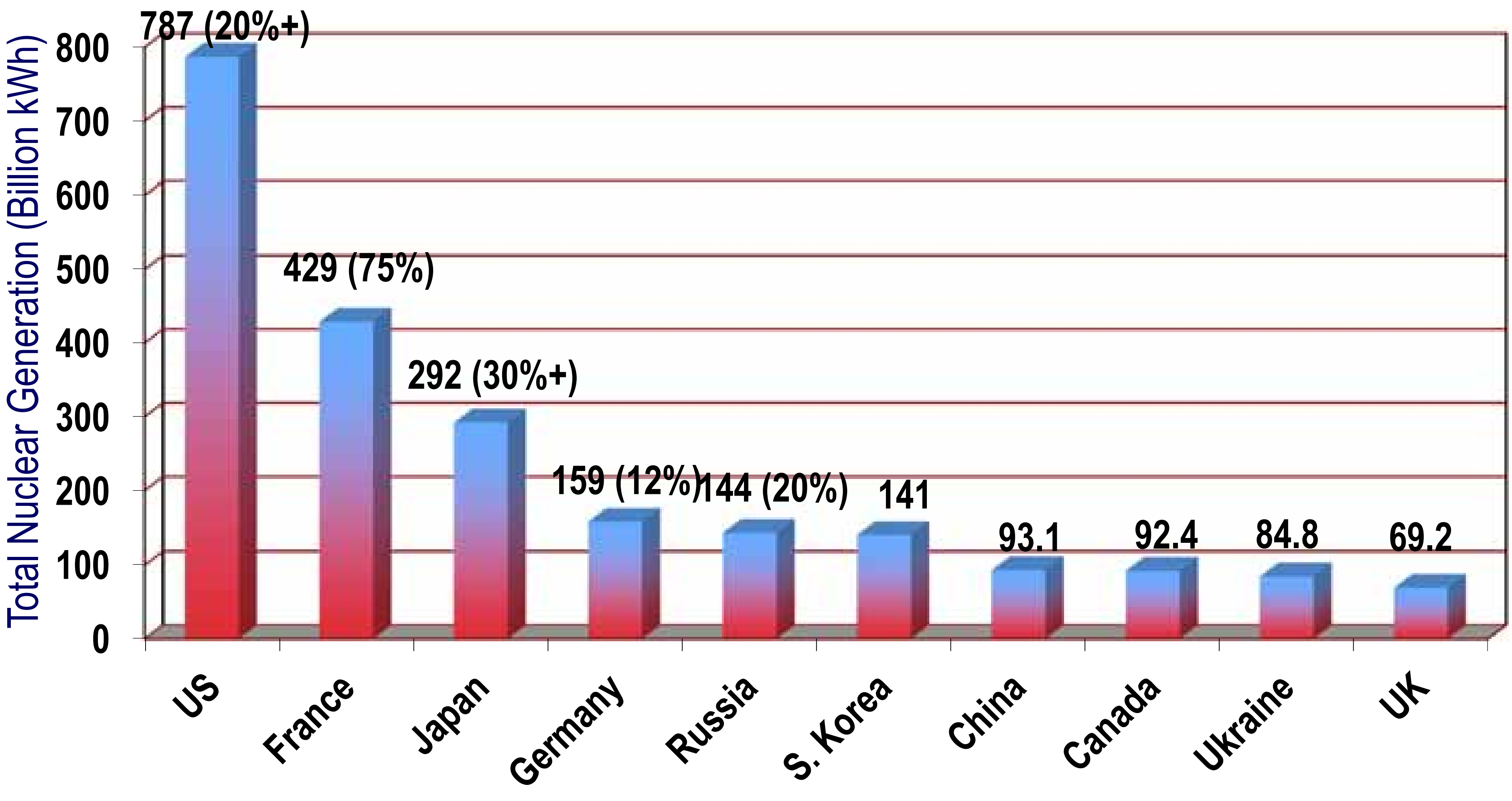
- Should TEPCO have anticipated a tsunami run-up of 14m?
- The recurrence interval for a large-scale tsunami is 800 to 1100 years. After Jogan 869, was 3/11 2011

| Year of big tsunami | Name or region | Mag | Height or traveled distance | Casualty |
|---|---|---|---|---|
| 869 | Jogan | 8.6 | 4 km | ~1,000 |
| 1611 | Keicho | 8.1 | | 2,000~3,000 |
| 1793 | Sanriku | 8.4 | ? | 9 |
| 1856 | Sanriku | 7.5 | ? | 30 |
| 1896 | Meiji-sanriku | 7.2 | 38 m | 22,000~27,000 |
| 1933 | Sanriku | 8.4 | 28.7 m | 1,500~3,000 |
| 1952 | Kamchatka | 9.0 | 1-3 m | - |
| 1960 | Chile | 9.5 | 5-6 m | 142 |
| 1968 | Tokachi-oki | 7.9 | 3-5 m | 52 |




*Source "A PRA Practitioner looks at the Great East Japan Earthquake and Tsunami" White Paper by Woody Epstein's May, 2011, Tokyo Institute of Technology

# Who uses Nuclear Power?

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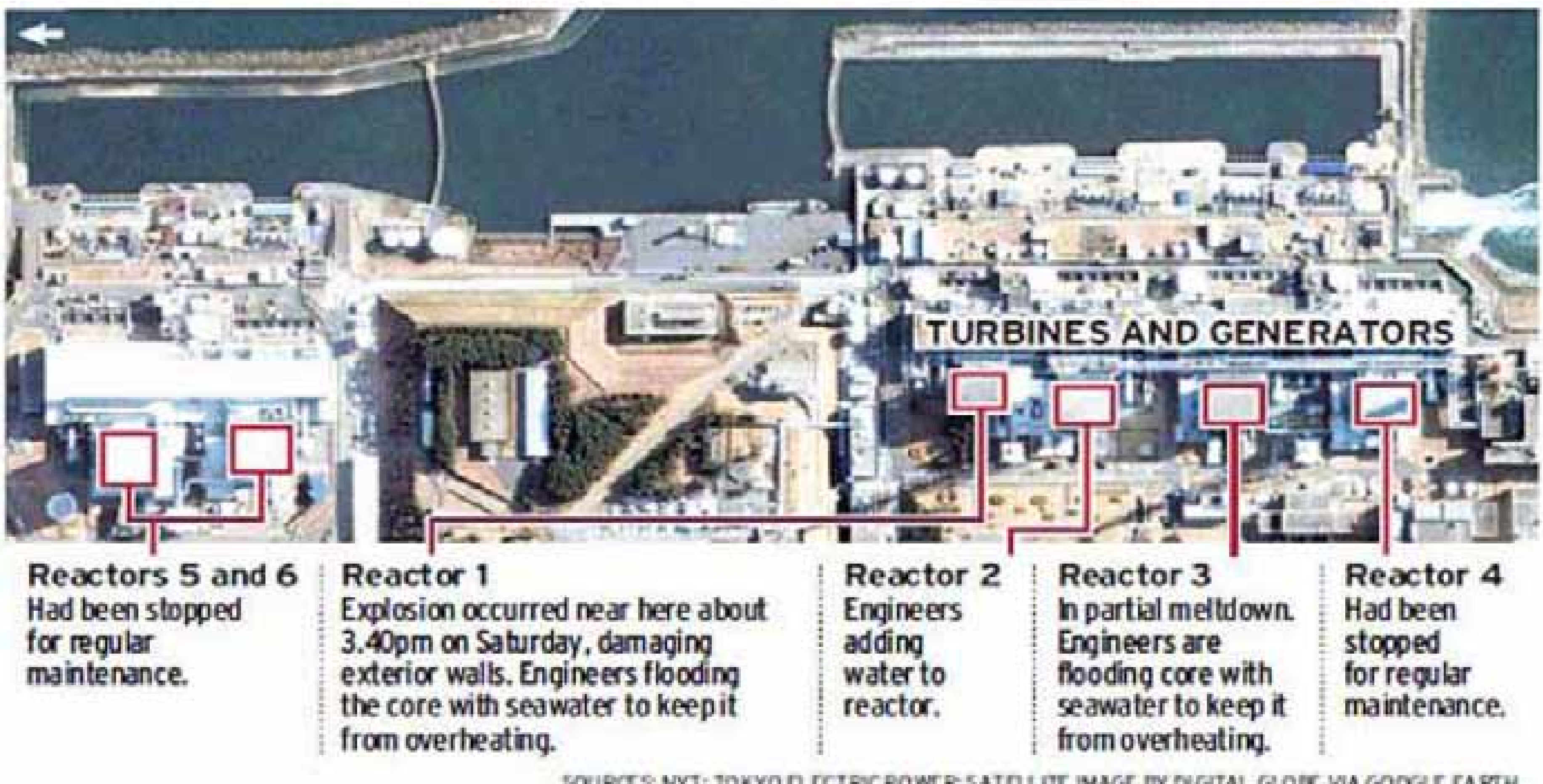
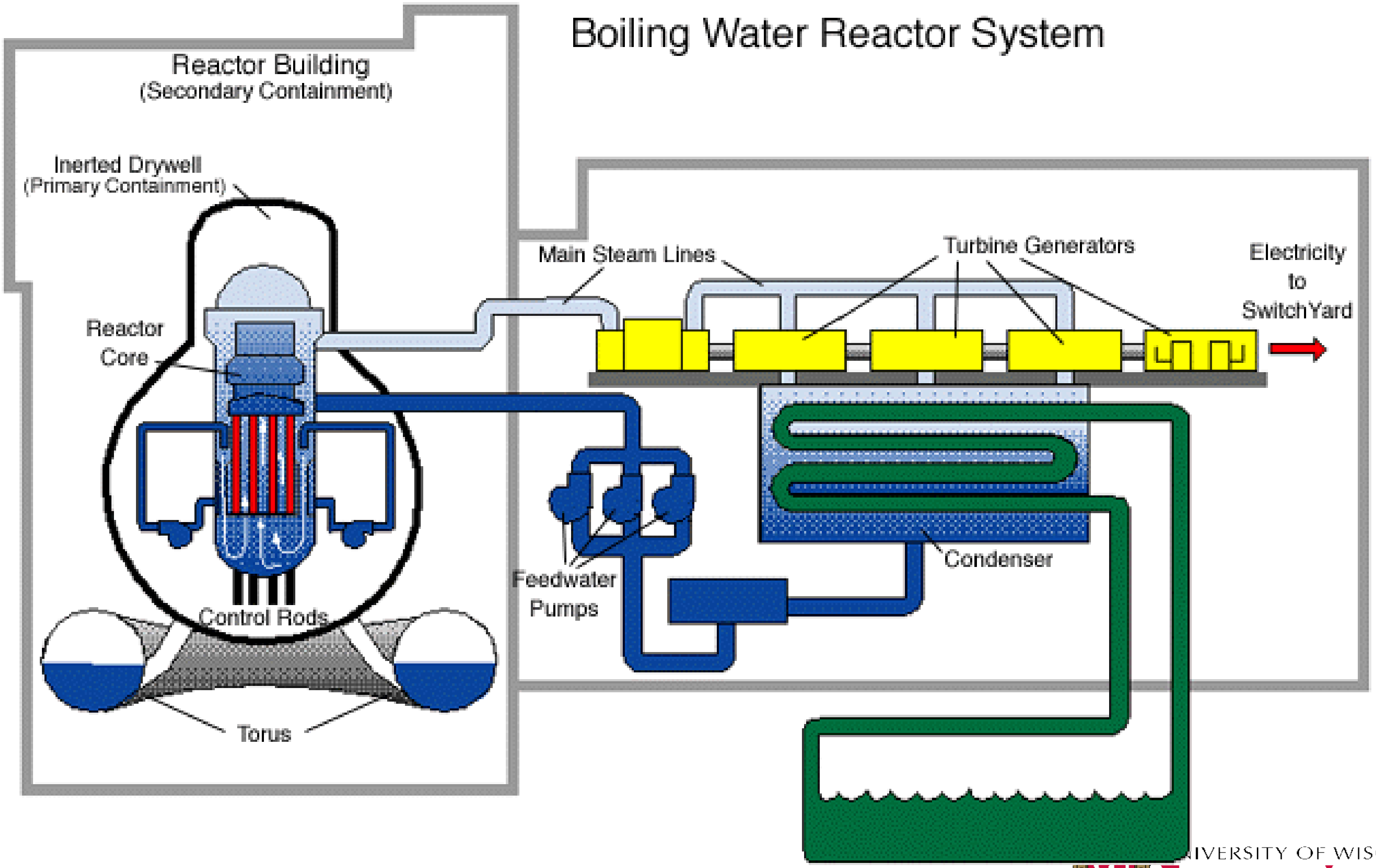
- **Six BWR units at the Fukushima Nuclear Station:**
  - Unit 1: 439 MWe BWR, 1971 (unit was in operation prior to event)
  - Unit 2: 760 MWe BWR, 1974 (unit was in operation prior to event)
  - Unit 3: 760 MWe BWR, 1976 (unit was in operation prior to event)
  - Unit 4: 760 MWe BWR, 1978 (unit was in outage prior to event)
  - Unit 5: 760 MWe BWR, 1978 (unit was in outage prior to event)
  - Unit 6: 1067 MWe BWR, 1979 (unit was in outage prior to event)

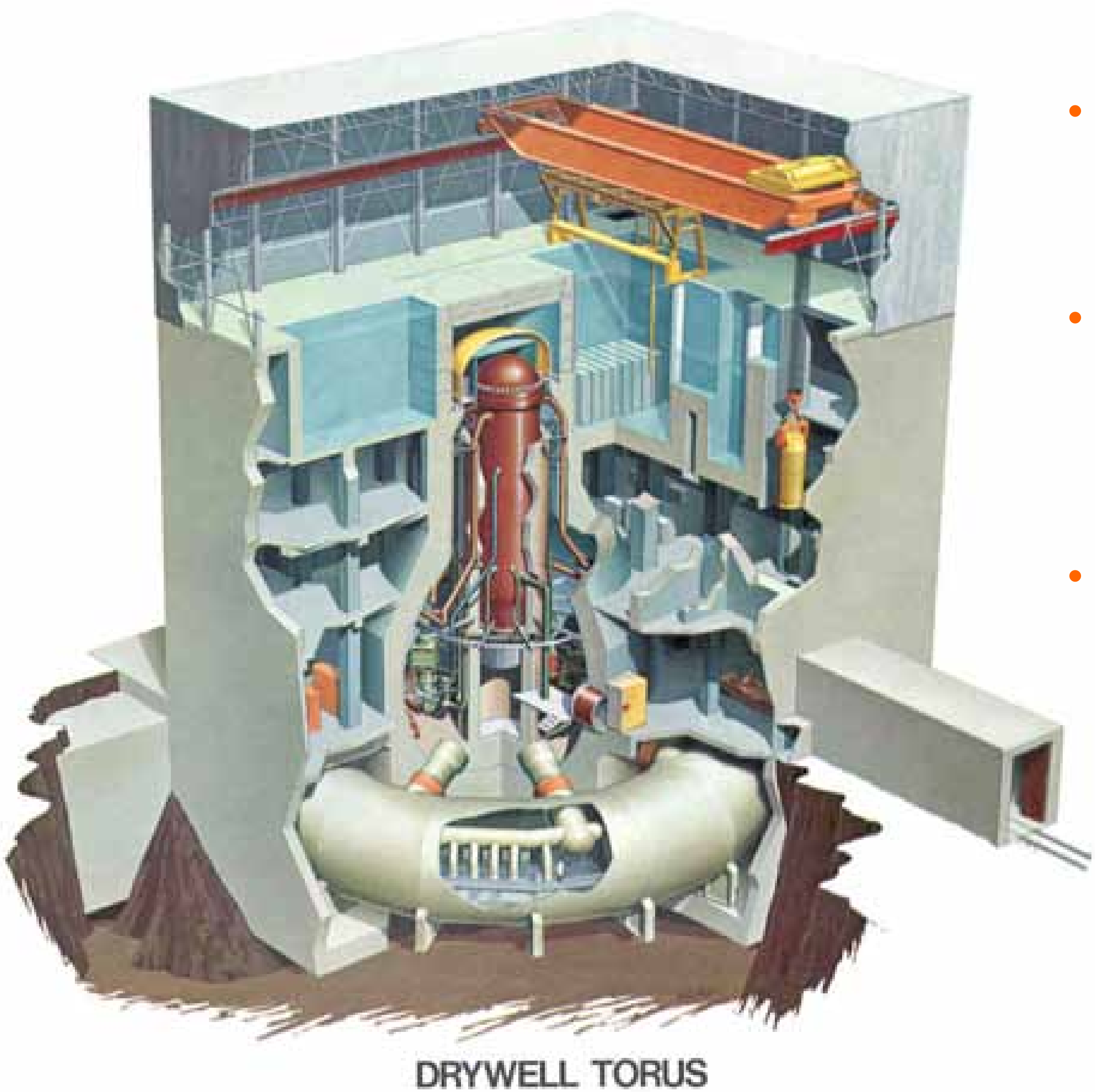


# Overview of Boiling Water Reactor

- Typical BWR 3 and 4 Reactor Design
- Some similarities to Duane Arnold Power Plant in Iowa



# GE Mark 1 Reactor Building




- There are 23 reactors in the United States utilizing Mark I containments.
- Available data suggests similarities exist in the design and operation of Japanese and US Mark I containments.
- Following 9/11, the NRC required licensee's to develop comprehensive beyond design basis mitigation strategies (i.e. procedures, staging of portable equipment).



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# Browns Ferry Primary Containment

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# Fukushima Daiichi Unit 1

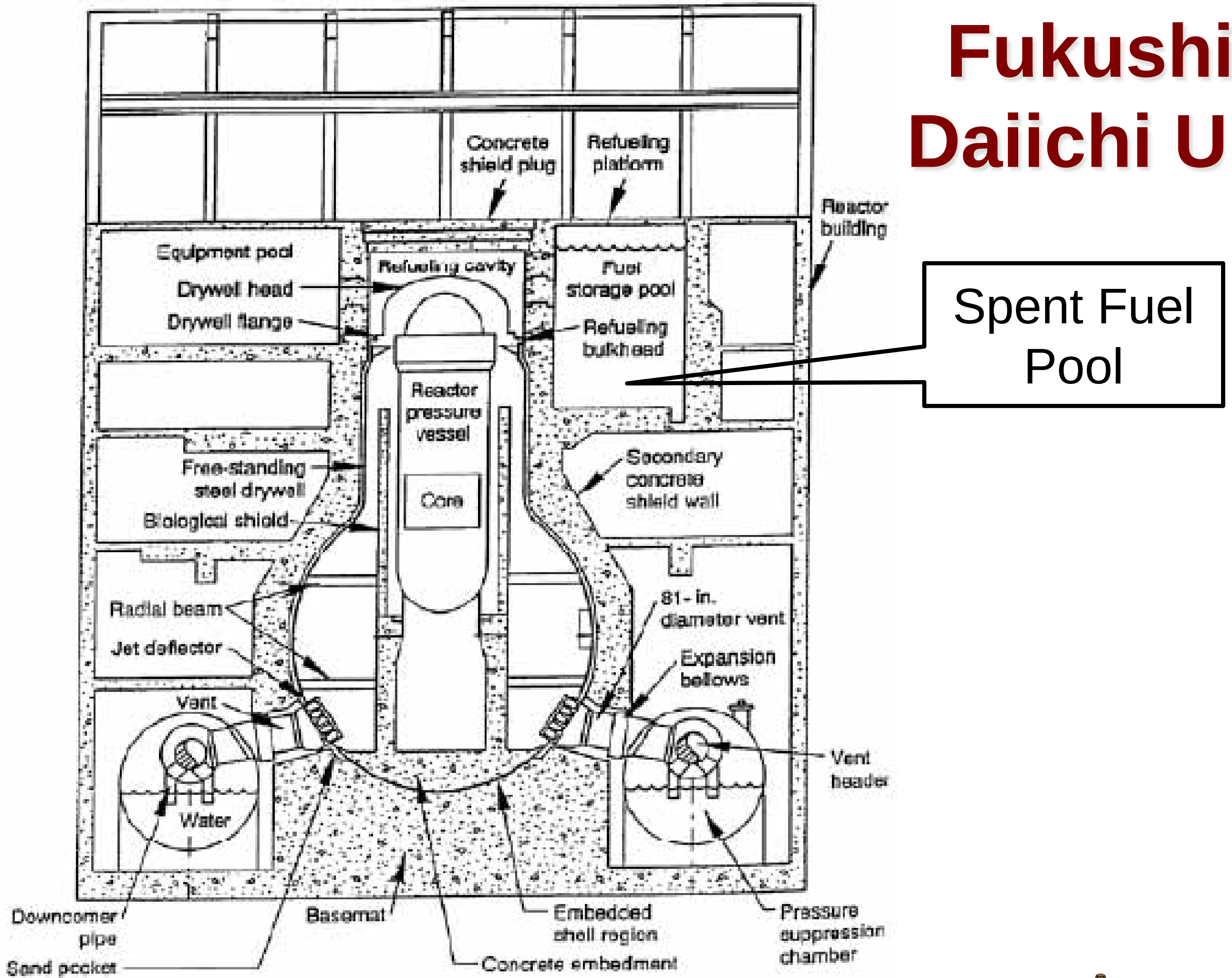


Figure 20. Mark I General Electric,GE BWR Containment.



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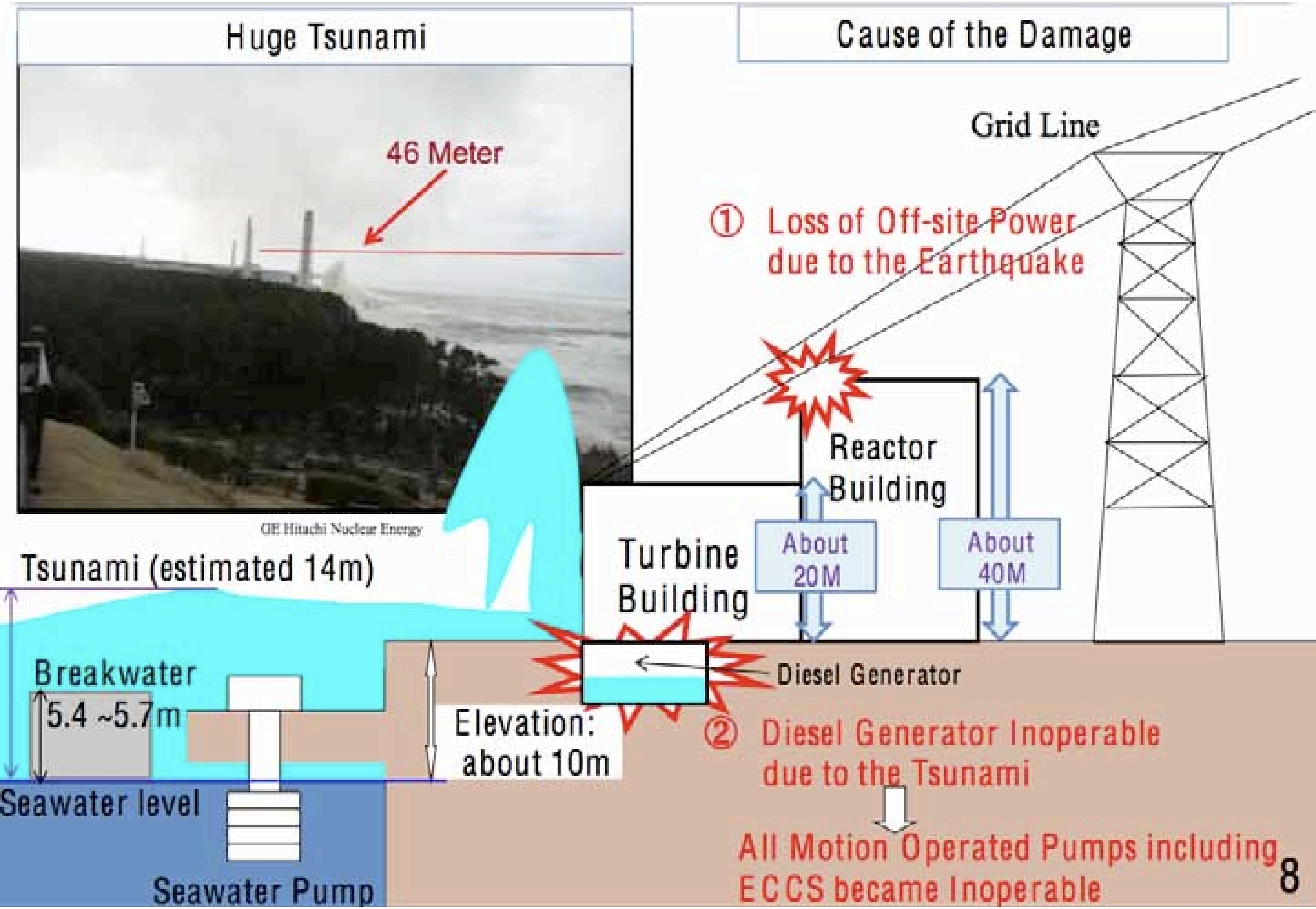
# Accident Description at Fukushima Dai-ichi site

- Discuss accident sequence for Units at Fukushima Dai-ichi?
- What happened to the spent fuel pools in each unit?
- Why did Dai-ini and Osanawa plants survive the earthquake and tsunami?
- What was the command and control structure in Japan as compared to the U.S.?
- What were the EPG's and SAMG's for the Japanese plants and how different in U.S.?

# Fukushima Accident Initiation

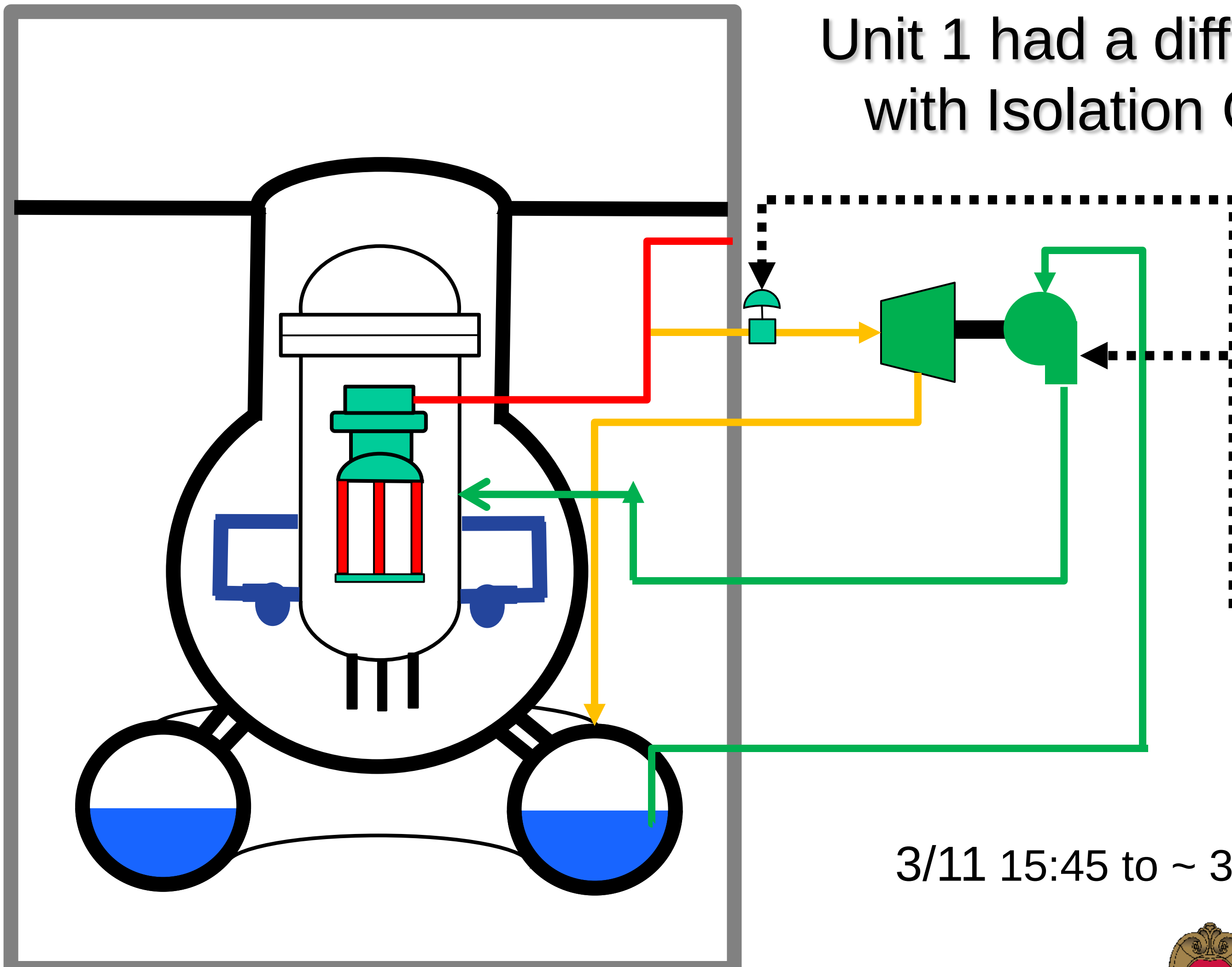


# Initial Accident Response

- Nuclear reactors were shutdown automatically.  Within seconds the control rods were inserted into core and nuclear chain reaction stopped.
- Cooling systems were placed in operation to remove the decay heat. The decay heat load decreased to < 1% after a day to 0.25% after 30 days.
- Earthquake resulted in the loss of offsite power which is the normal electricity supply to a plant when the nuclear reactor is shutdown.
- Emergency Diesel Generators powered station emergency cooling systems.
- One hour later, the station was struck by the tsunami. The tsunami was much larger than what the plant was designed for (14m waves) The tsunami took out all multiple sets of the Emergency Diesel generator, AC buses and likely damaged the service water pumps which provide cooling from the sea.
- Reactor operators used emergency battery power for cooling the reactors.
- Operators followed the emergency operating procedures.

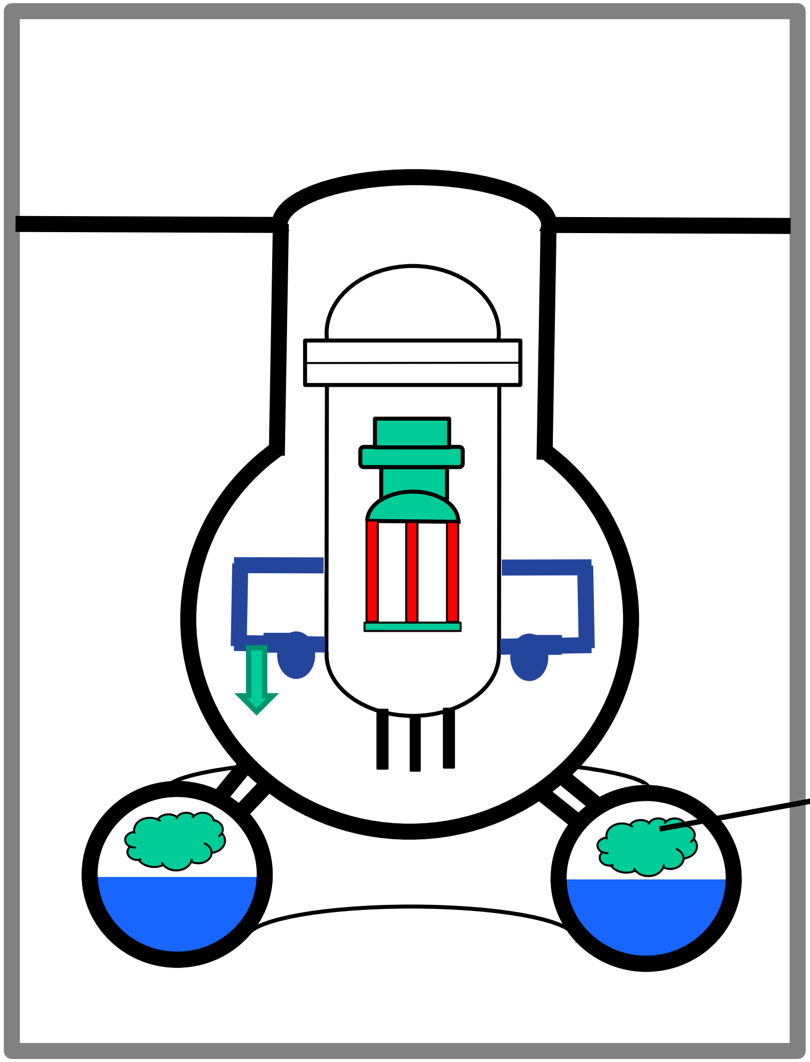
# Unit 2 & 3 Battery Power Controlled Steam-Driven Reactor Core Isolation Cooling (RCIC) System

Unit 1 had a different design with Isolation Condenser




3/11 15:45 to ~ 3/11 24:00 JST

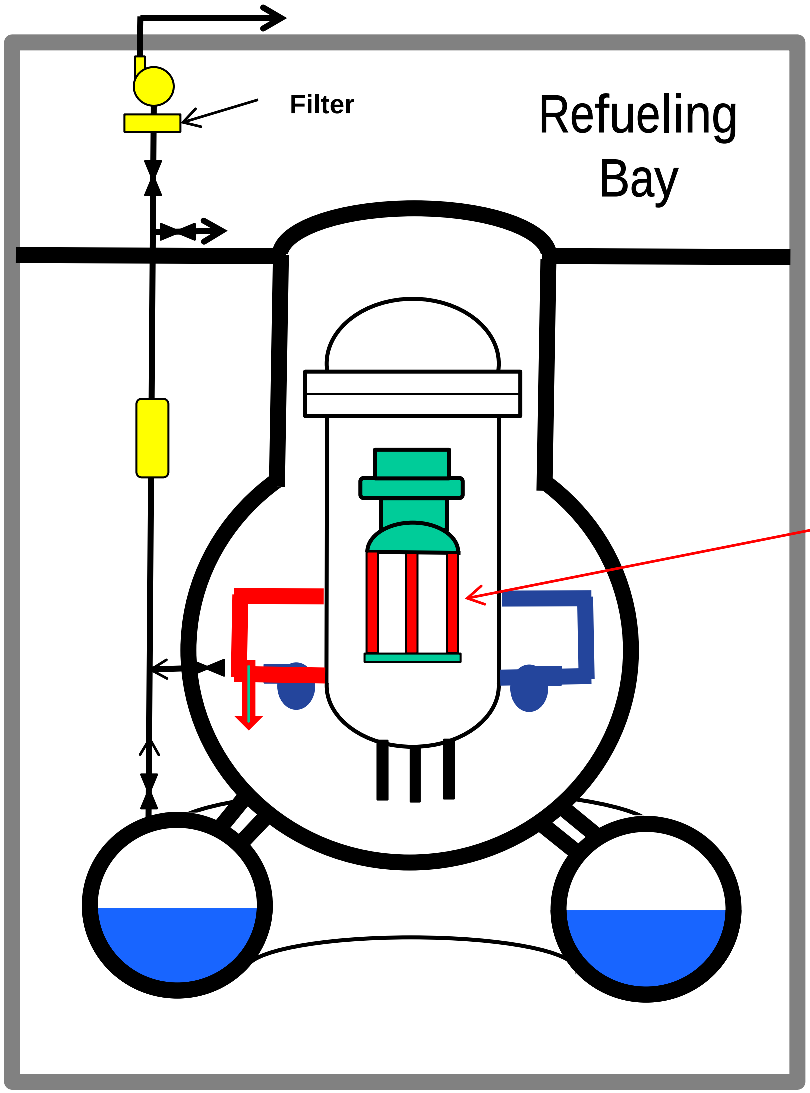
# Battery Power Exhausted by Sat: but RCIC was manually operated for at least another day by the operators



Suppression pool (wet well) becomes saturated and cooling degraded

3/12-13 ~02:00 JST

# Venting Primary Containment

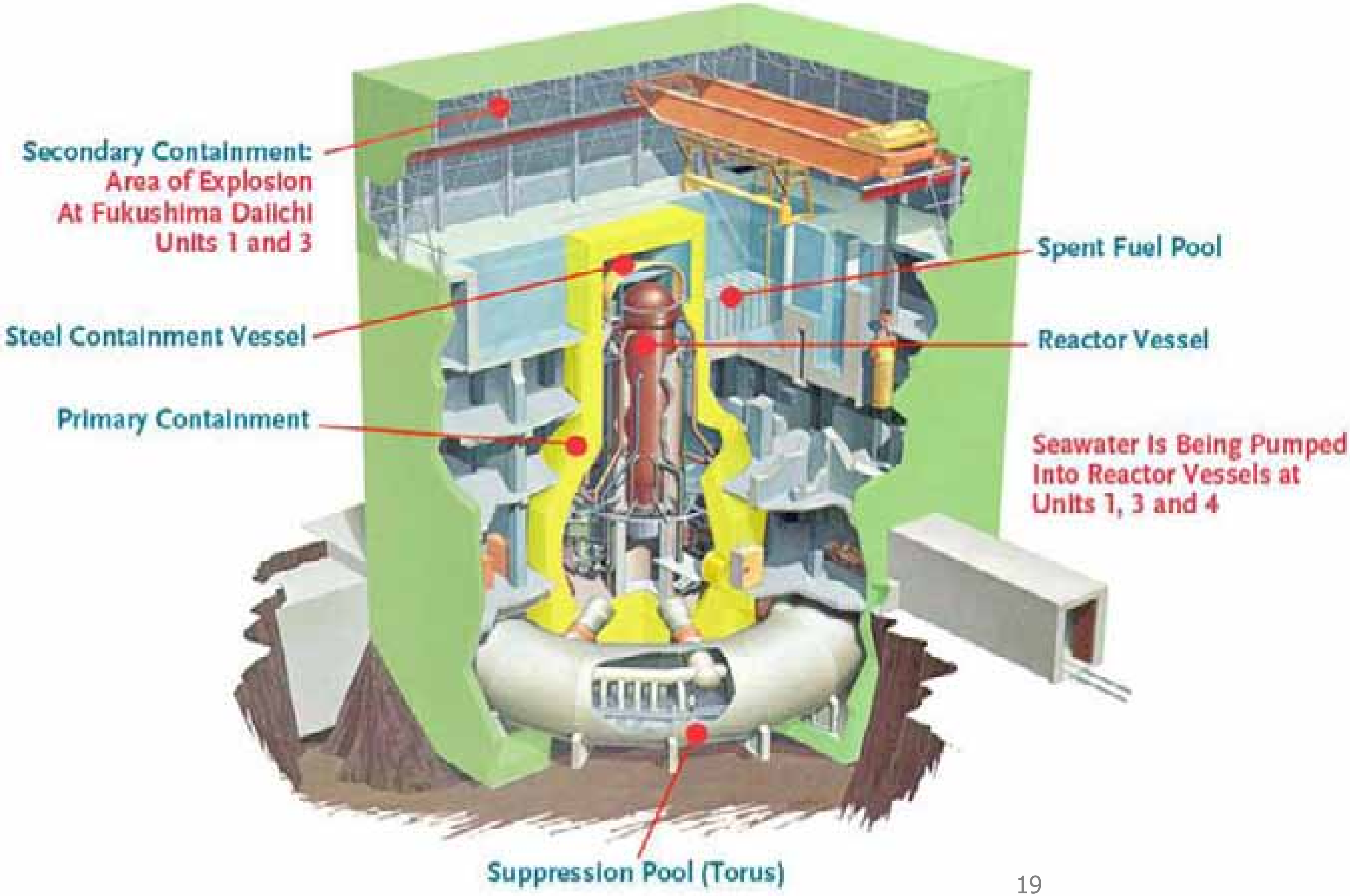



**Reactor Core Overheated**

Primary Containment Pressure~ 100psi

3/12 ~ 05:30 U1
3/13 ~ 00:00 U2
3/13 ~ 08:40 U3

# Fukushima Containment System



# Hydrogen Explosion in all the Units


Reactor Building

Refuel Floor


# Unit 4 Reactor Building: Hydrogen Explosion


**Hydrogen Explosion**

- Unit 1: March 12 15:36 (Reactor Building)
- Unit 2: March 15, 6:00 (Torus?)
- Unit 3: March 14,11:01 (Reactor Building)
- Unit 4: March 15, 6:00 (Reactor Building)



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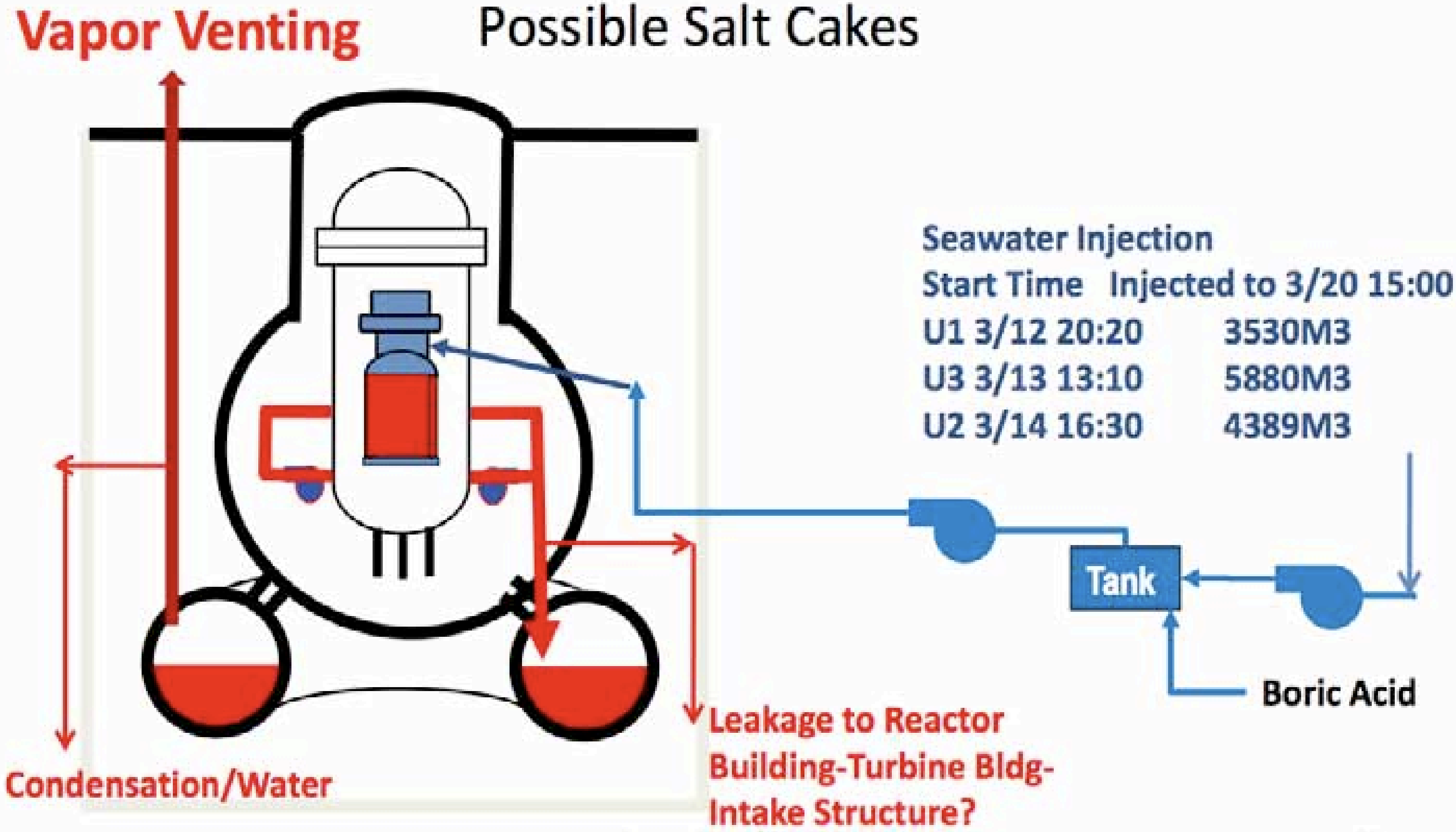
# Bleed & Feed Cooling Established

Seawater Injection Started Using Fire Engine Pump

Shift to Fresh Water Injection ~3/26-Present:To Dissolve Possible Salt Cakes



# Accident Description at Fukushima Dai-ichi site

- What happened to the spent fuel pools in each unit?

  From what is known spent fuel pools were not damaged

- Why did Dai-ini plants survive the earthquake and tsunami?

  Dai-ini plants were in a bay which mitigated the tsunami

- What was the command and control structure in Japan as compared to the U.S.? In the U.S. the plant manager on-duty has complete authority during any site emergency

- What were the EPG's and SAMG's for the Japanese plants and how different in U.S.? As far as we know the procedures were similar for the Japanese plants

# Health effects of Radioisotope Release

- What was the emergency response for general public?
- What were the on-site dose effects to workers?
- What were the off-site dose effects to the public?
- What were the long-term land contamination effects off-site?
- What were the ramifications of the evacuation zones chosen by Japan and U.S.?

# Emergency Response

- General Emergency declared to the initial events in Unit 1 on Friday.
- Evacuation of public performed within 20 km of plant; approximately 200,000 people evacuated and sheltered in place within 30km.
- Recorded radiation levels spiked after each explosion (above).
- The NRC's radiation dose limit for the public is 100 mrem/yr (1000μSv/yr) and natural background is about 300 mrem/yr (3000μSv/yr or 0.34μSv/hr).
- Several workers reported with radiation exposure: two above 25 rem.
- Potassium-iodide tablets given to protect the public from potential health effects of radioactive isotopes of iodine that could potentially be released.
- 100's aftershocks have occurred and challenge station response.

# Spatial Dose Rate Comparisons - March 18th

**Avg. Radiation Doses**

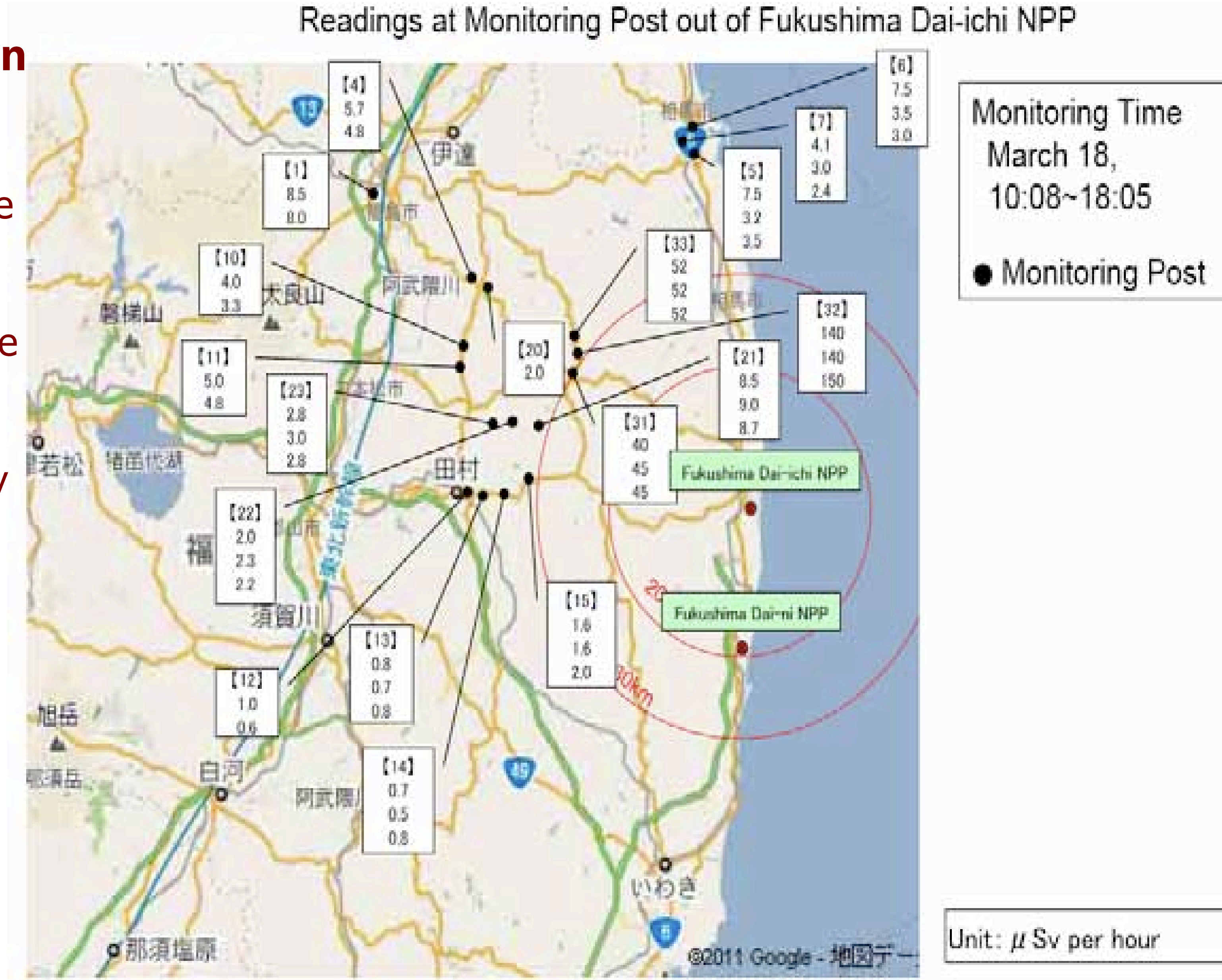
U.S. Natural Dose (0.34 μSv/hr)

U.S. Medical Dose (0.37 μSv/hr)

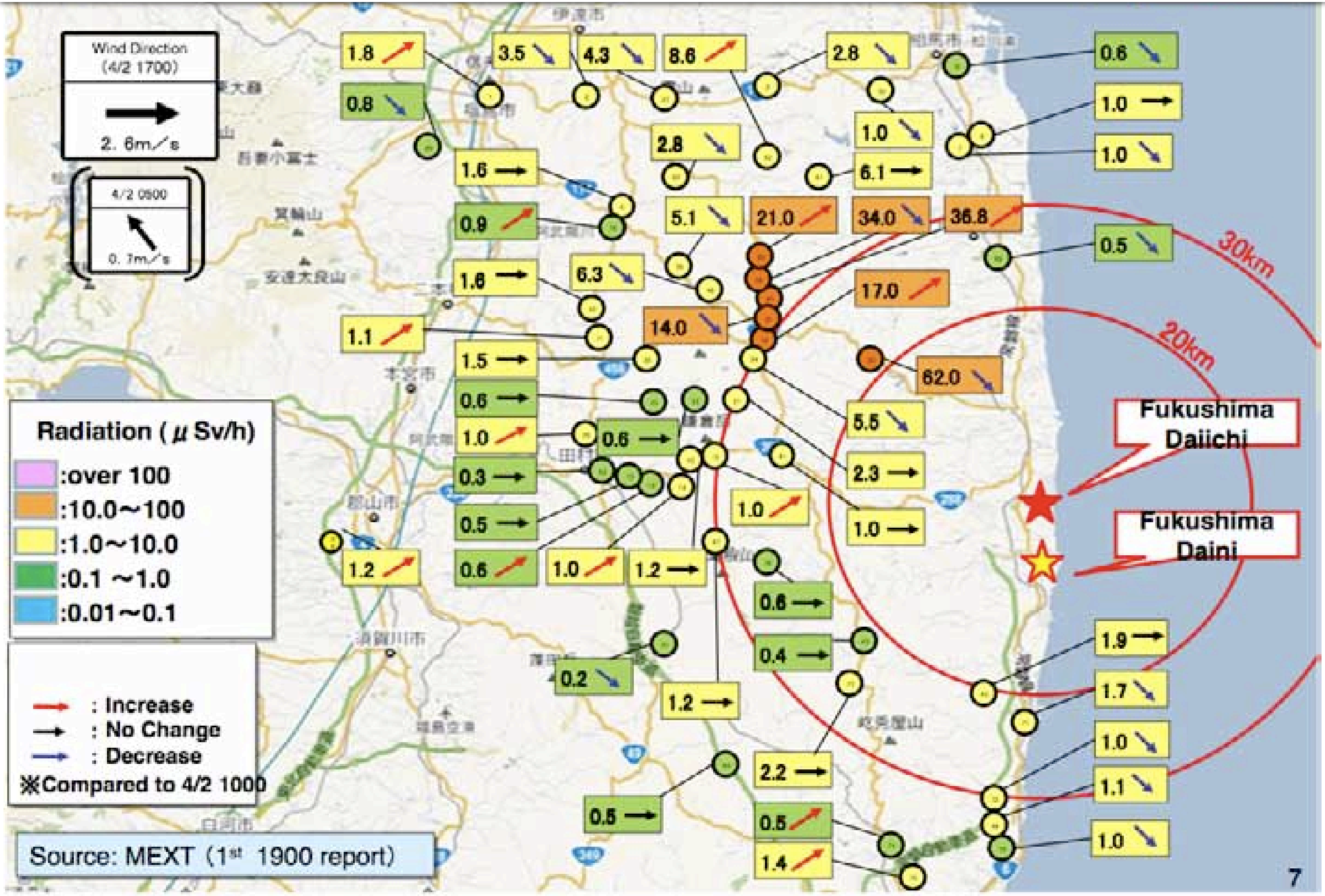
Single Chest Xray (40 μSv)

Mammogram (300 μSv)

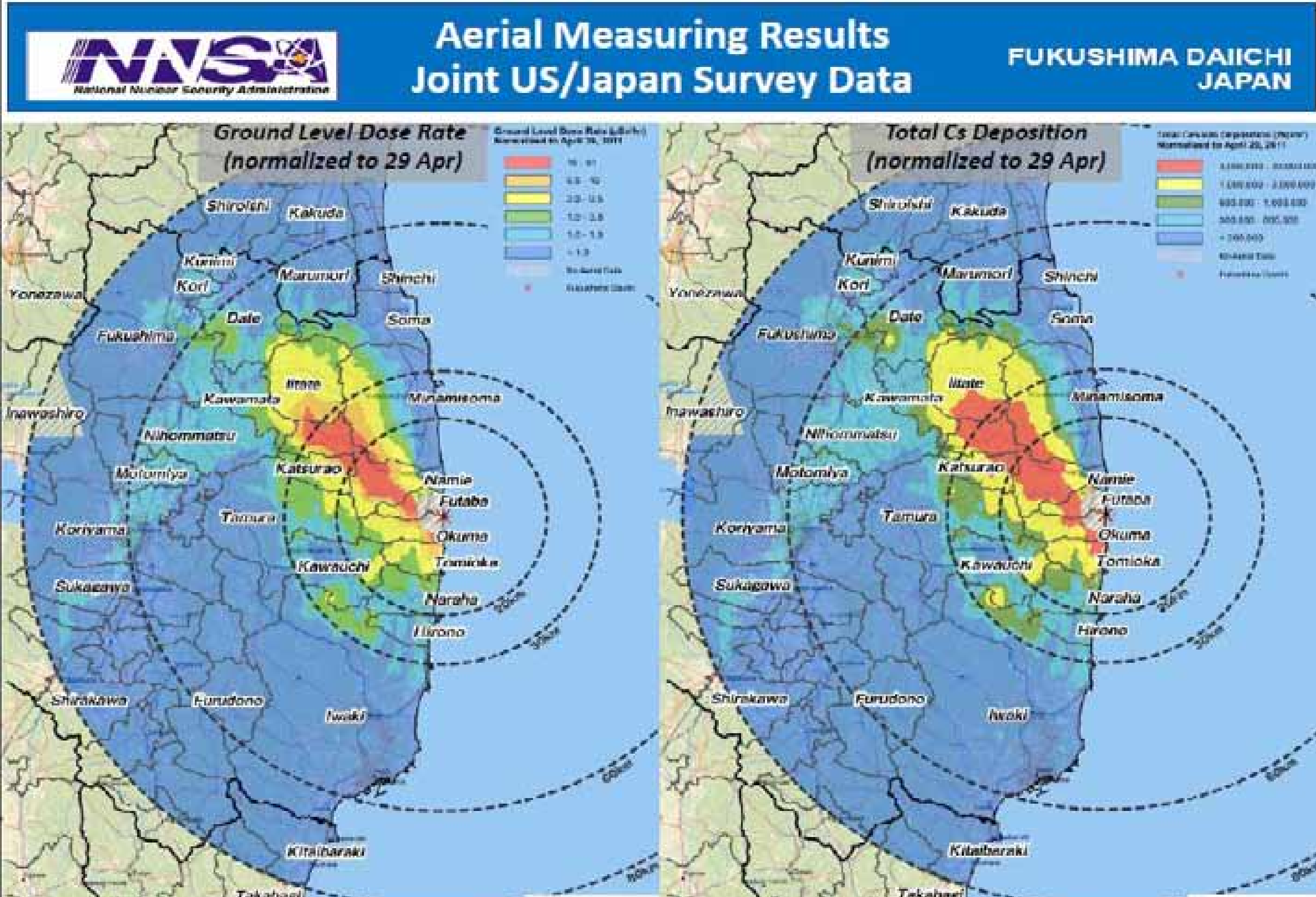
LA-to-NYC flight (20 μSv/trip)



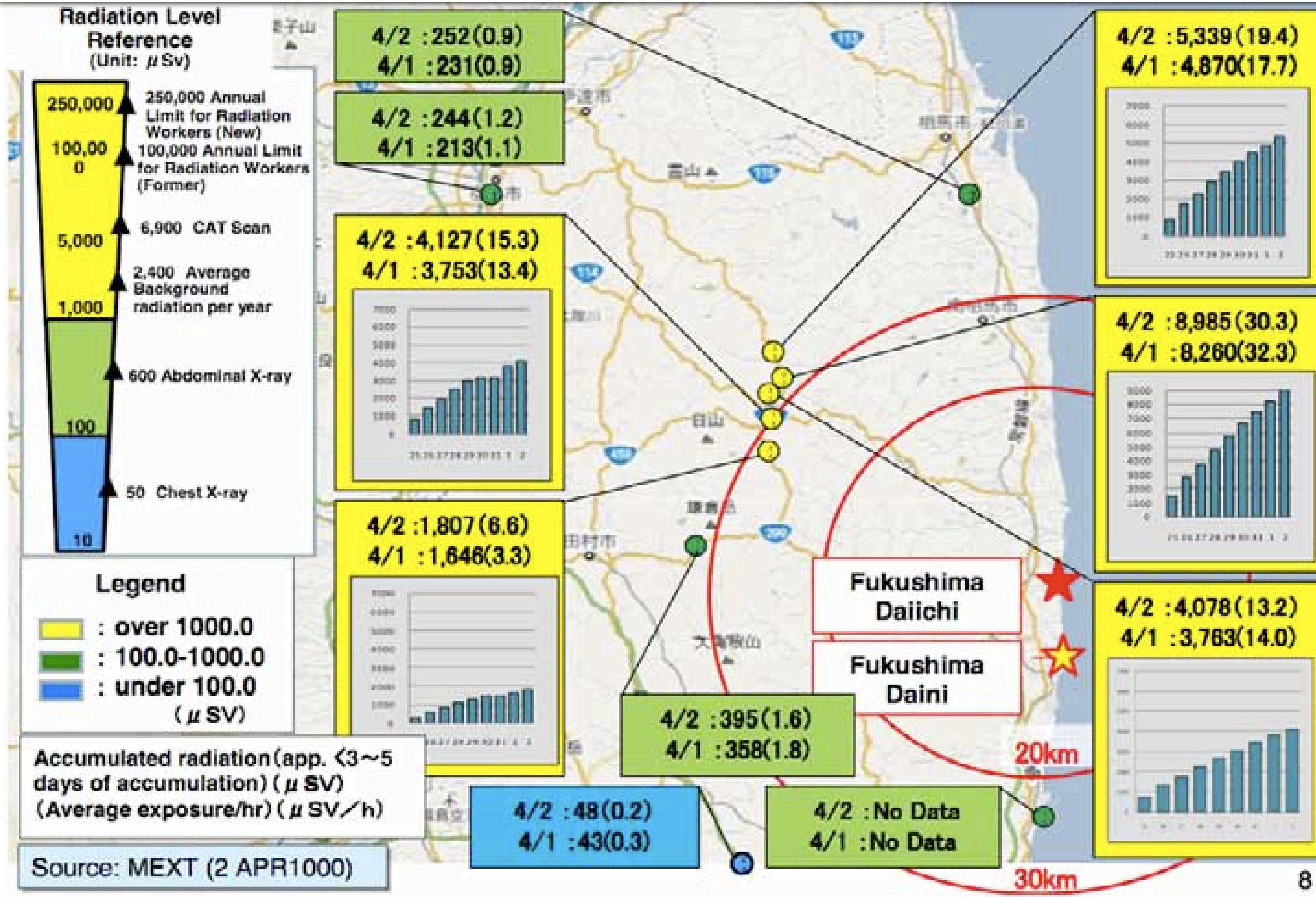
# Spatial Dose Rate Comparisons – April 1st



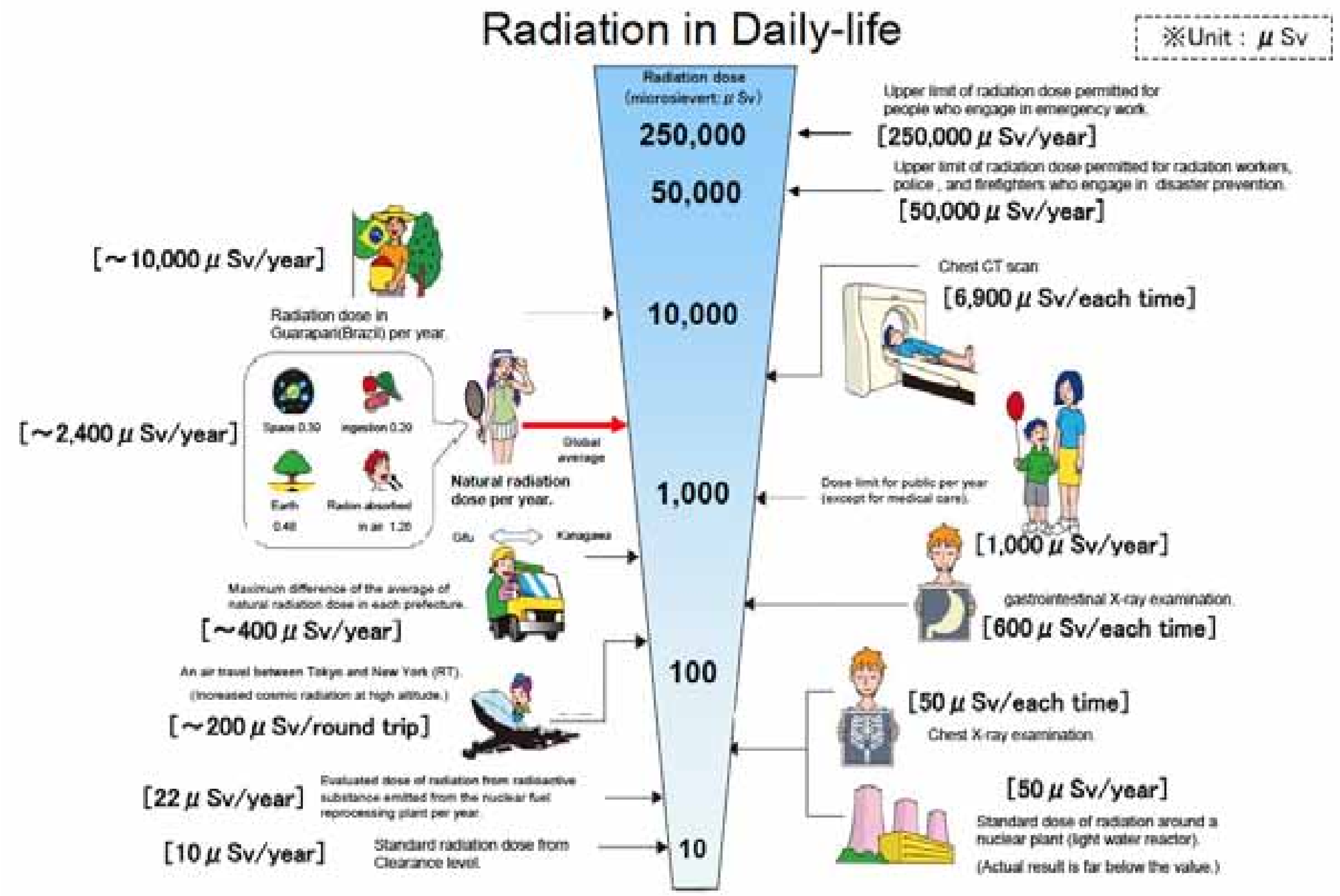
# Integrated Dose Comparisons to May 1st



# Integrated Dose Comparisons to May 1st



# Radiation Levels Put Into Context




http://www.mext.go.jp/english/radioactivity_level/detail/1303962.htm

# Lessons-Learned from the Fukushima Event

- Command/control of an accident needs to reside as close to the accident location as possible; plant manager on-site needs to retain absolute control to assure safety is ‘main focus’
- Coping with a station blackout could be accommodated for longer periods of time with innovative plant modifications
- Spent fuel cooling was maintained but uncertainty suggests that better instrumentation and assured cooling water needed
- Modifications after 911 may be used as added safety systems
- Severe accident management guidelines need to be reviewed
- Regulatory structure in countries need to conform to IAEA std

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# Risk Communication: Accident Comparison

- Chernobyl released over 10 times more radioactive material over a few days due to the explosion
- TMI released over 10 times less radioactive material
- Earthquake and Tsunami damage was extensive (28,000 dead/missing; disaster costs range from $250-500b)
- Fukushima accident has not caused any loss of life but is estimated to cost 5-10% of this total damage (estimate of latent cancers ~10's out of 10's millions)
- Chernobyl accident early fatalities were over 50 with ~5000 cases of children treated with thyroid cancer
- TMI cost ~$2b on-site with off-site damages $150m, and no deaths or statistically significant latent effects

# Roadmap towards Settling the Situation of Fukushima Dai-ichi Accident

| | Step1<br>Around 3 Months | Step 2<br>Around 3 to 6 Months<br>(after achieving step 1) |
|---|---|---|
| Target | Radiation Dose in Steady Decline | Controlling Release of Radioactive Materials<br>(significant reduction of dose level) |
| Reactors | Stable Cooling<br>(flooding up to top of active fuel) | Achieving Cold Shutdown |
| Spent Fuel Pools | Stable Cooling | More Stable Cooling<br>(keeping sufficient level of water by remote-control) |
| Contaminated Water | Prevention of Outflow to the outside of the Site | Decreasing Contaminated Water<br>(decontamination and desalt) |
| Contaminated Atmosphere/Soil | Prevention of Spread | Covering Up the Entire Reactor Building<br>(as temporary measure) |

April 17, TEPCO

# References


## Japan's Countermeasures

- 1.http://www.kantei.go.jp/foreign/incident/index.html
- 2.http://www.meti.go.jp/english/index.html
- 3.http://www.nisa.meti.go.jp/english/

## Measurement of Radioactivity Level

- 1.http://www.mext.go.jp/english/radioactivity_level/detail/1303962.htm
- 2.http://www.nisa.meti.go.jp/english/
- 3.http://www.worldvillage.org/fia/kinkyu_english.php
- 4. http://www.tepco.co.jp/en/press/corp-com/release/index-e.html

## Drinking Water Safety

- 1.http://www.mhlw.go.jp/english/topics/2011eq/index.html
- 2.http://www.waterworks.metro.tokyo.jp/press/shinsai22/press110324-02-1e.pdf

## Food Safety

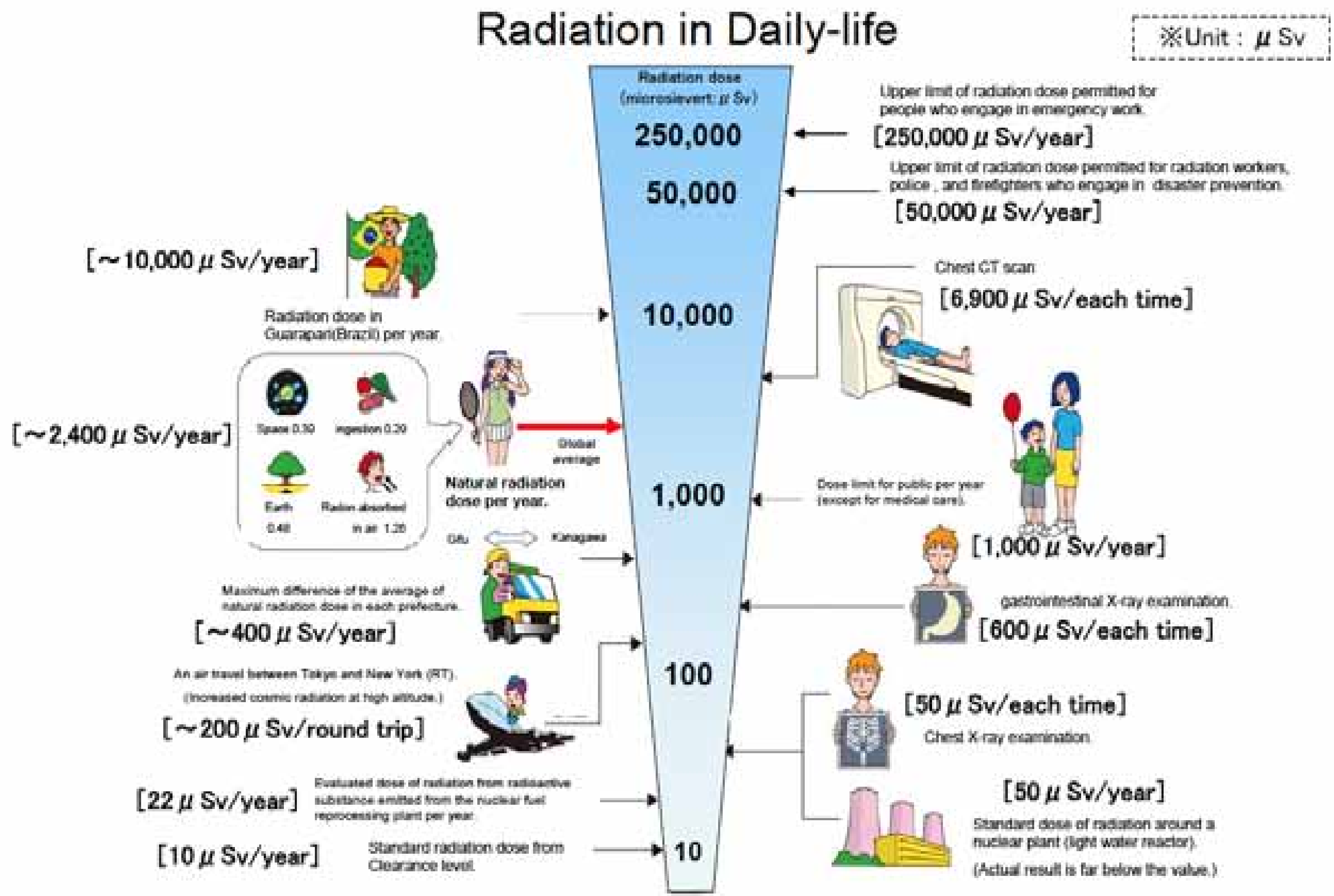
- 1.http://www.maff.go.jp/e/index.html
- 2.http://www.mhlw.go.jp/english/topics/2011eq/index.html

## Ports and Airports Safety

- 1.http://www.mlit.go.jp/page/kanbo01_hy_001428.html
- 2.http://www.mlit.go.jp/koku/flyjapan_en/index.html
- 3.http://www.mlit.go.jp/page/kanbo01_hy_001411.html

# Backup Slides

# Radiation Levels Put Into Context




http://www.mext.go.jp/english/radioactivity_level/detail/1303962.htm

# Short-Term Health Risks

| Exposure (Sv) | Exposure (µSv - microSv) | Health Effect |
|---|---|---|
| 0.05 | 50,000 | changes in blood chemistry |
| 0.5 | 500,000 | nausea |
| 0.55 | 550,000 | fatigue |
| 0.7 | 700,000 | vomiting |
| 0.75 | 750,000 | hair loss |
| 0.9 | 900,000 | diarrhea |
| 1 | 1,000,000 | hemorrhage |
| 4 | 4,000,000 | possible death (2 months) |
| 10 | 10,000,000 | death (1-2 weeks) |
| 20 | 20,000,000 | death (hours-days) |

Public not at risk for any short-term health effects.

# Long-Term Health Risks

Above 0.1 Sv (100,000 μSv) the cancer risk can be approximated by using 5% per Sv (accepted via the linear dose model).

- For example, the occupational worker who received as dose of 0.1 Sv has a 0.5% increased risk of developing a cancer in their life.
- Estimating cancer risks to the general public is difficult because of the low dose rates outside of the plant and large overall cancer rates.
- If radiation levels in Tokyo remained at the current level (0.14 μSv/hr) it would take one month of exposure for residents to experience the same risks than received from a common dental X-ray exam.

# Release Inventory

Uranium and Transuranium Elements

| Isotopes | Half life |
|---|---|
| Pu-238 | 88 – years |
| Pu-239 | 24,200 – years |
| Pu-240 | 6563 – years |
| U-234 | 246,000 – years |
| U-235* | 7.0E+08 – years |
| U-238* | 4.5E+09 – years |
| Am-241 | 432 – years |
| Cm-242 | 160 – days |

*naturally occurring

**50% of all Iodine was released**
**1% of all Cesium was released**
**Minimal amount of Sr released**

Fission Products

| Isotopes | Half life |
|---|---|
| I-131 | 8 – days |
| I-132 | 2 – hours |
| Cs-134 | 2 – years |
| Cs-137 | 30 – years |
| Te-129m | 34 – days |
| Te-132 | 3 – days |
| Ba-140 | 13 – days |
| Nb-95 | 35 – days |
| Ru-106 | 370 – days |
| Mo-99 | 66 – hours |
| Tc-99m | 6 – hours |
| Sr-90 | 29 – years |
| Ag-110m | 250 - days |

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# Dose to Employees

TEPCO released a report providing the number of workers that exceeded the emergency limit of 100 mSv per year.

| Dose Range (mSv) | Number of Workers |
|---|---|
| 100-150 | 2 |
| 150-200 | 8 |
| 200-250 | 11 |
| Total | 21 |

There have been no reported cases of acute radiation syndrome or deaths due to exposure. (Chernobyl: 134 workers developed ARS and 28 died)

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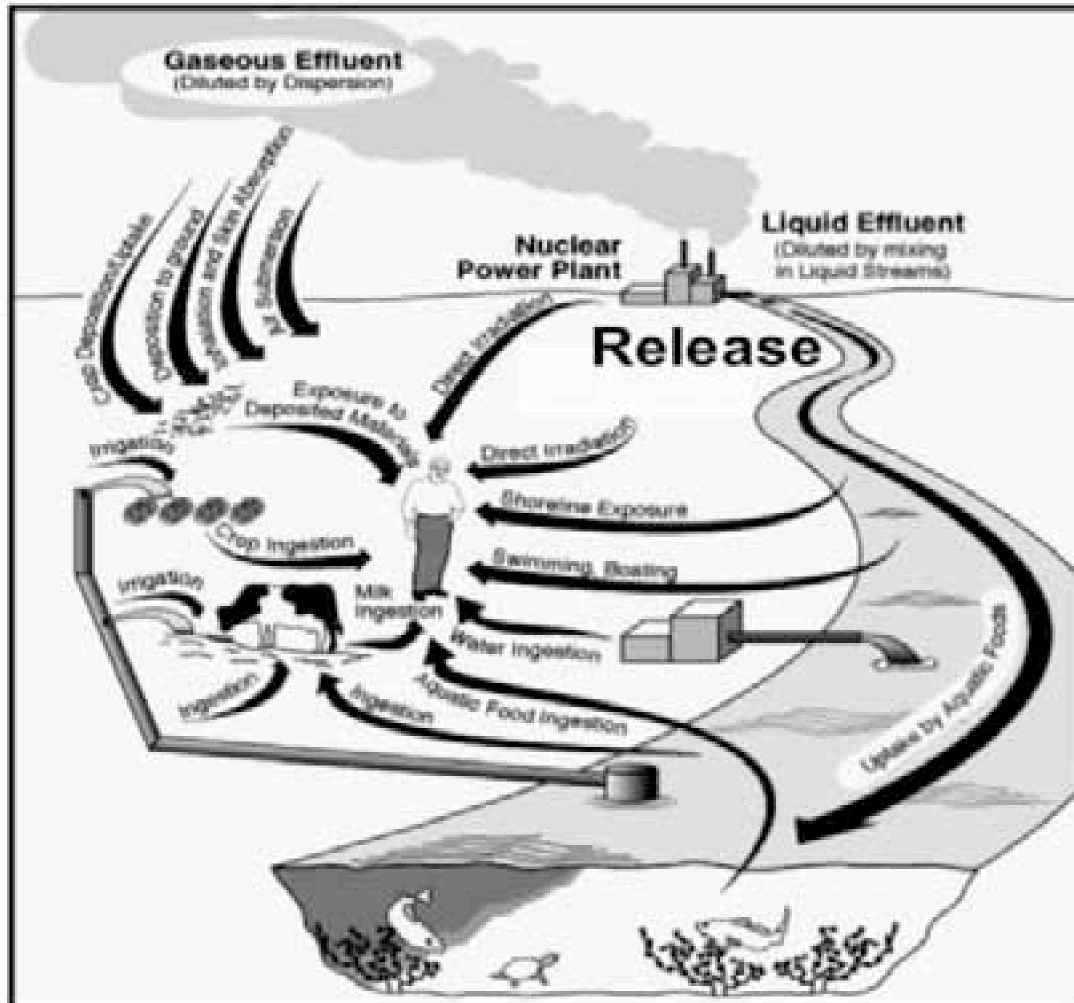
# Pathways To Humans

Pathways to humans is diverse:

- Air
- Water
- Soil




Source: ORNL/M-4227. Oak Ridge National Laboratory, Oak Ridge, TN.

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# Continuous Environmental Monitoring

| Monitoring | Onsite | Offsite |
|---|---|---|
| • Area Monitoring | O | O |
| • Air Monitoring | O | |
| • Soil Monitoring | O | O |
| • Water Monitoring | | |
| • Freshwater | | O |
| • Seawater | O | O |
| • Food | | O |

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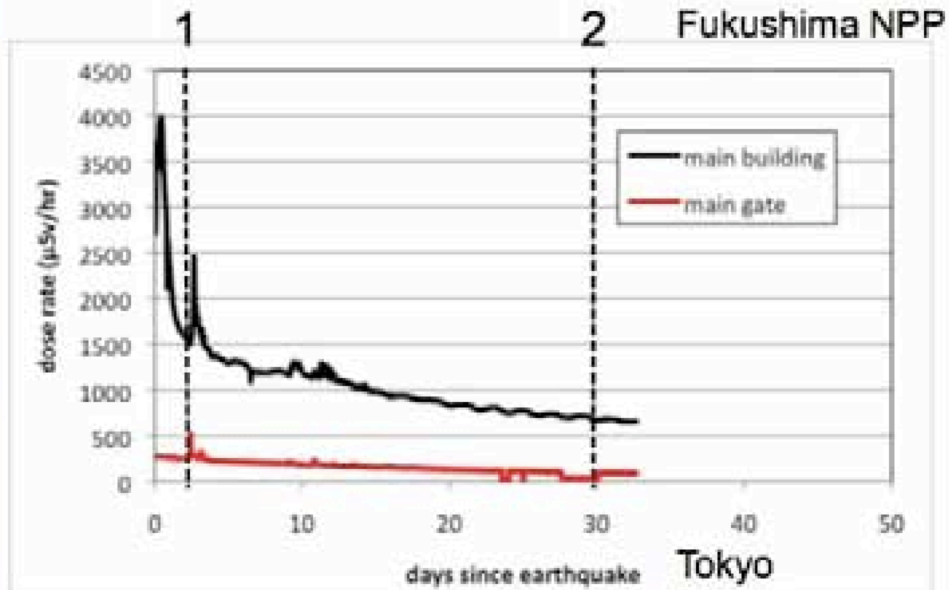
# Area Monitoring

(Onsite)






Source: NNSA. http://nnsa.energy.gov/mediaroom/pressreleases/fukushimadata

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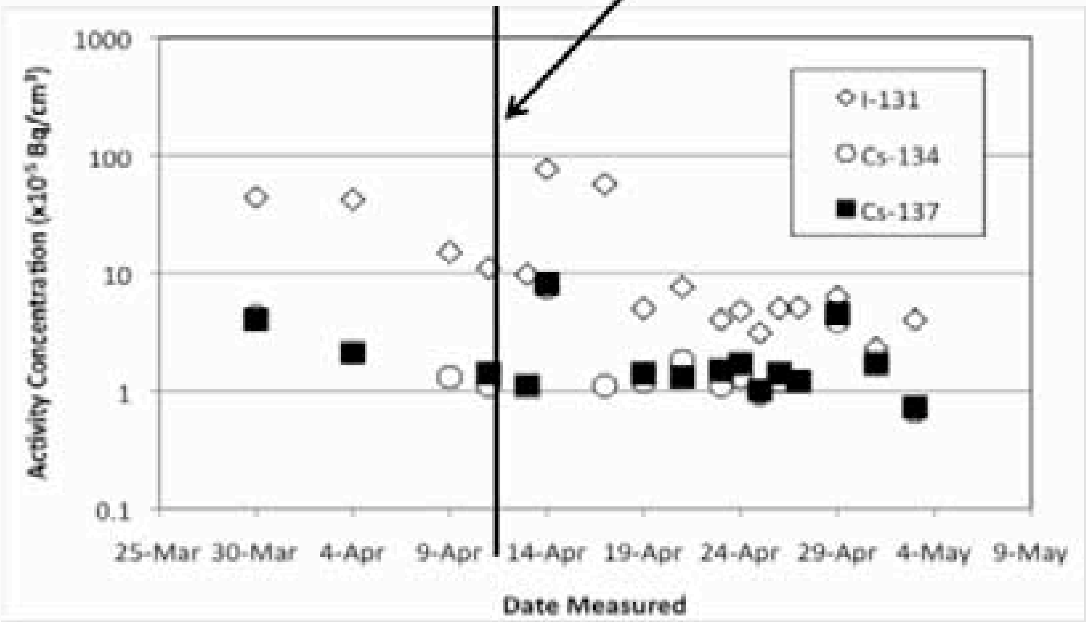
# Air Monitoring

(Onsite)

Fukushima NPP

Transfer of contaminated water from Unit 2 to condenser 4/12-4/13.



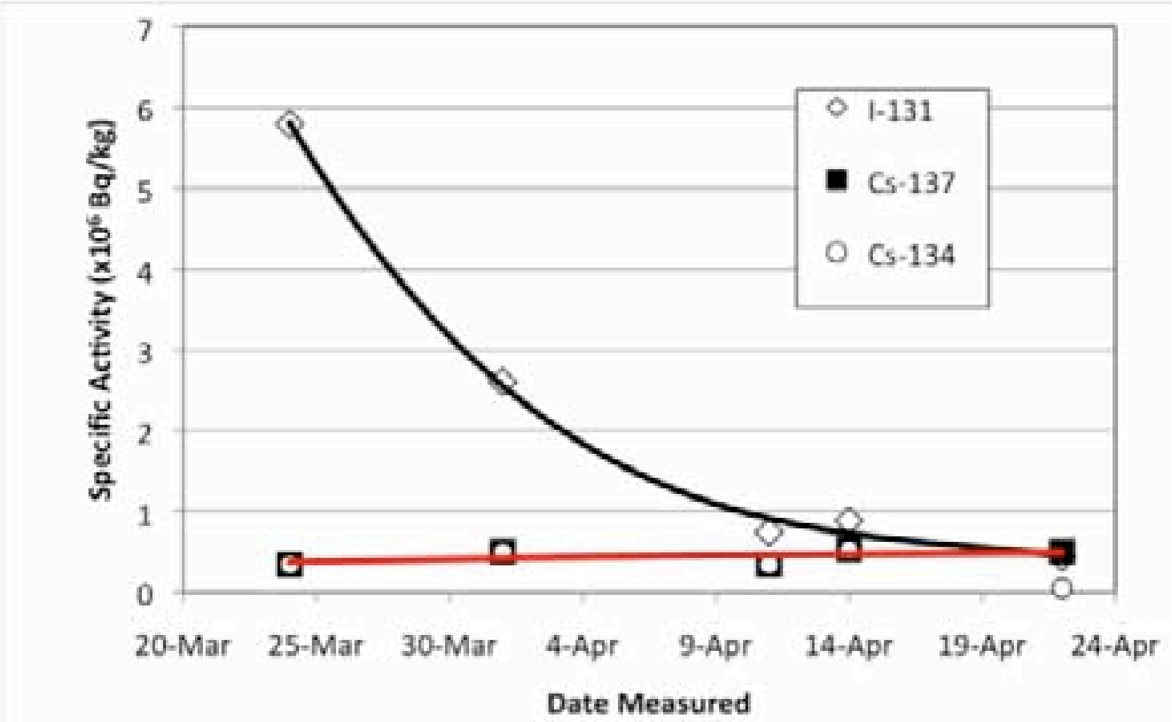

Important for monitoring internal exposures.

Source: TEPCO, http://www.tepco.co.jp/en/press/corp-com/release/index-e.html

# Soil Monitoring

(Onsite)

## Fukushima NPP




Source: TEPCO, http://www.tepco.co.jp/en/press/corp-com/release/index-e.html

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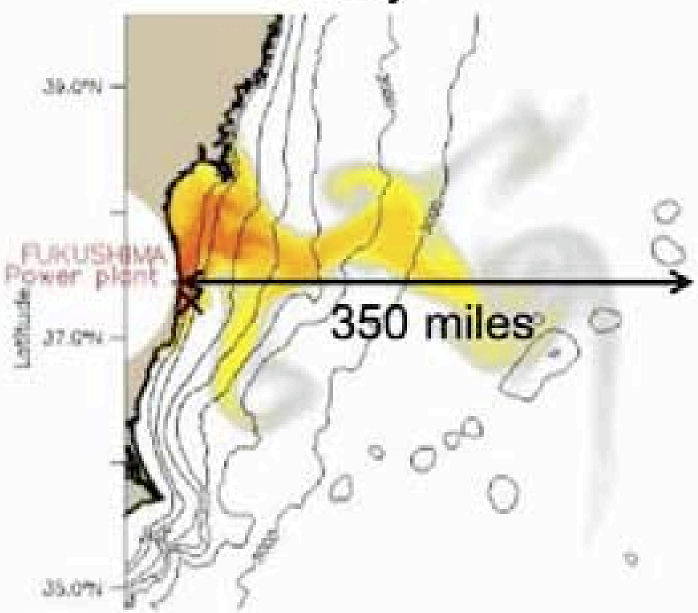
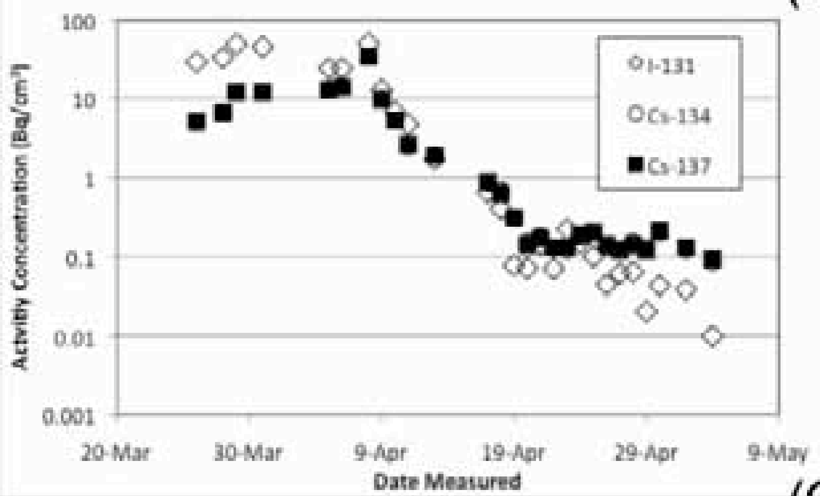
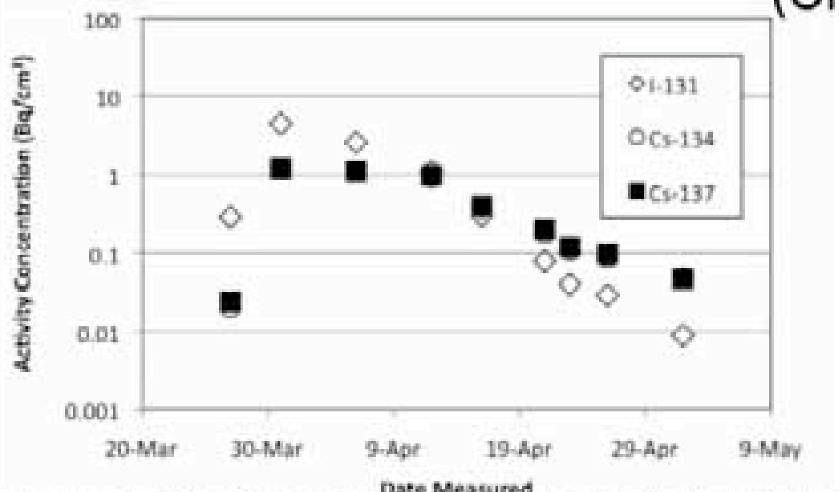
# Water Monitoring




(Onsite)




(Offsite)



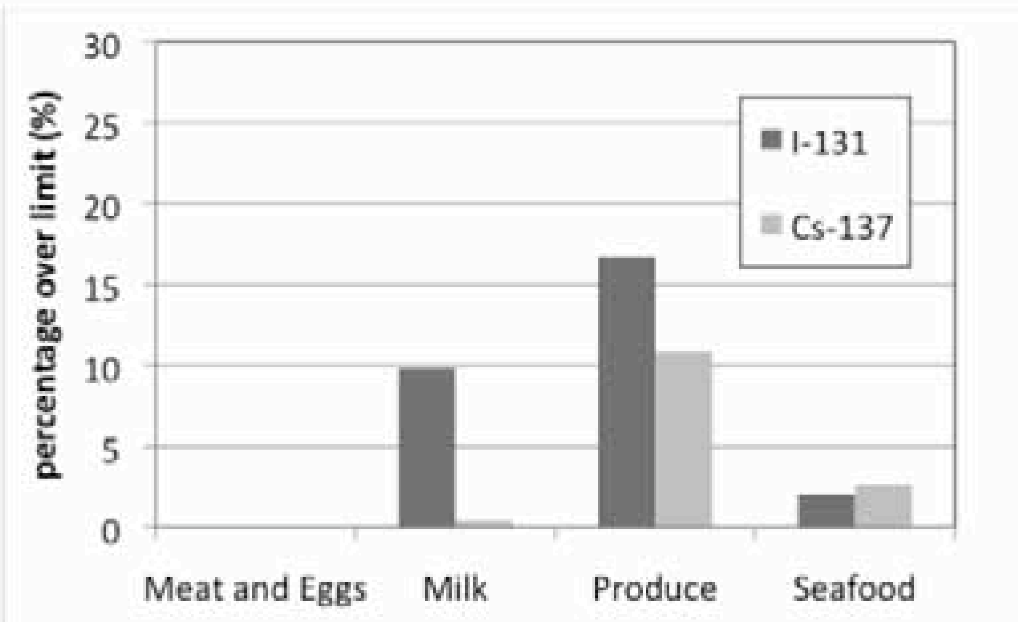

Source: TEPCO, http://www.tepco.co.jp/en/press/corp-com/release/index-e.html

Source: SIROCCO, http://sirocco.omp.obs-mip.fr/accueil/Accueil.htm

# Food and Water Monitoring

(Offsite)

6 out of 16 prefectures have tested positive for contamination in the food chain (Chiba, Gunma, Ibaraki, Fukushima, Saitama and Tochigi*)




*FDA has banned milk, milk products, vegetables, and fruits from the 6 prefectures

Source: WHO. Situation Report: Focus on food safety and water quality

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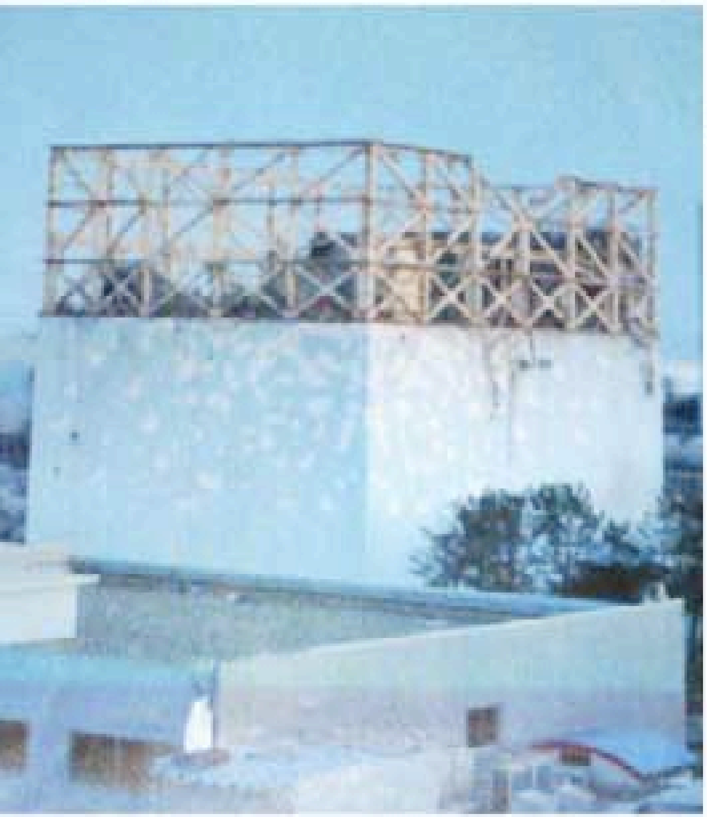
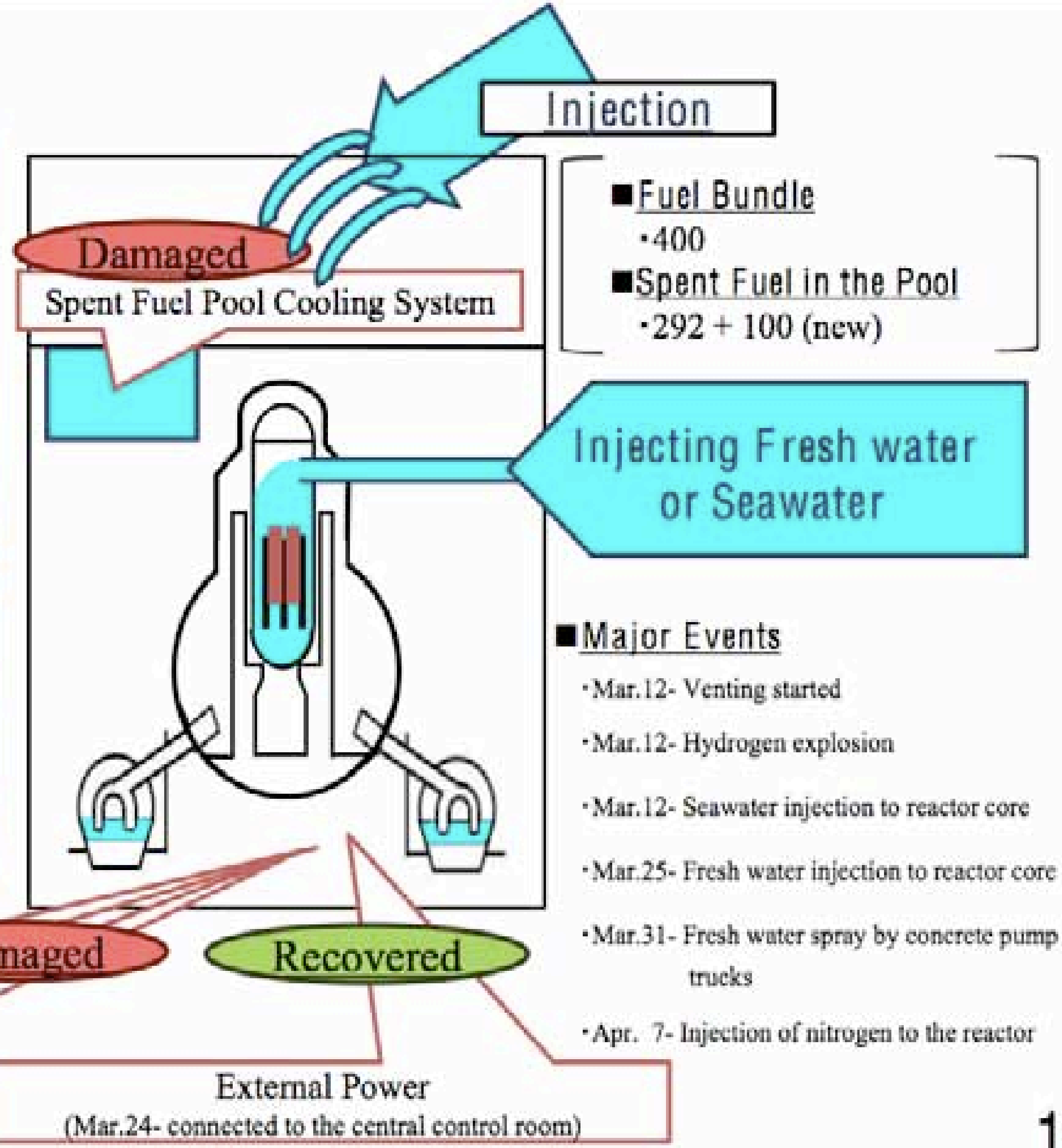
# Three Mile Island Comparison

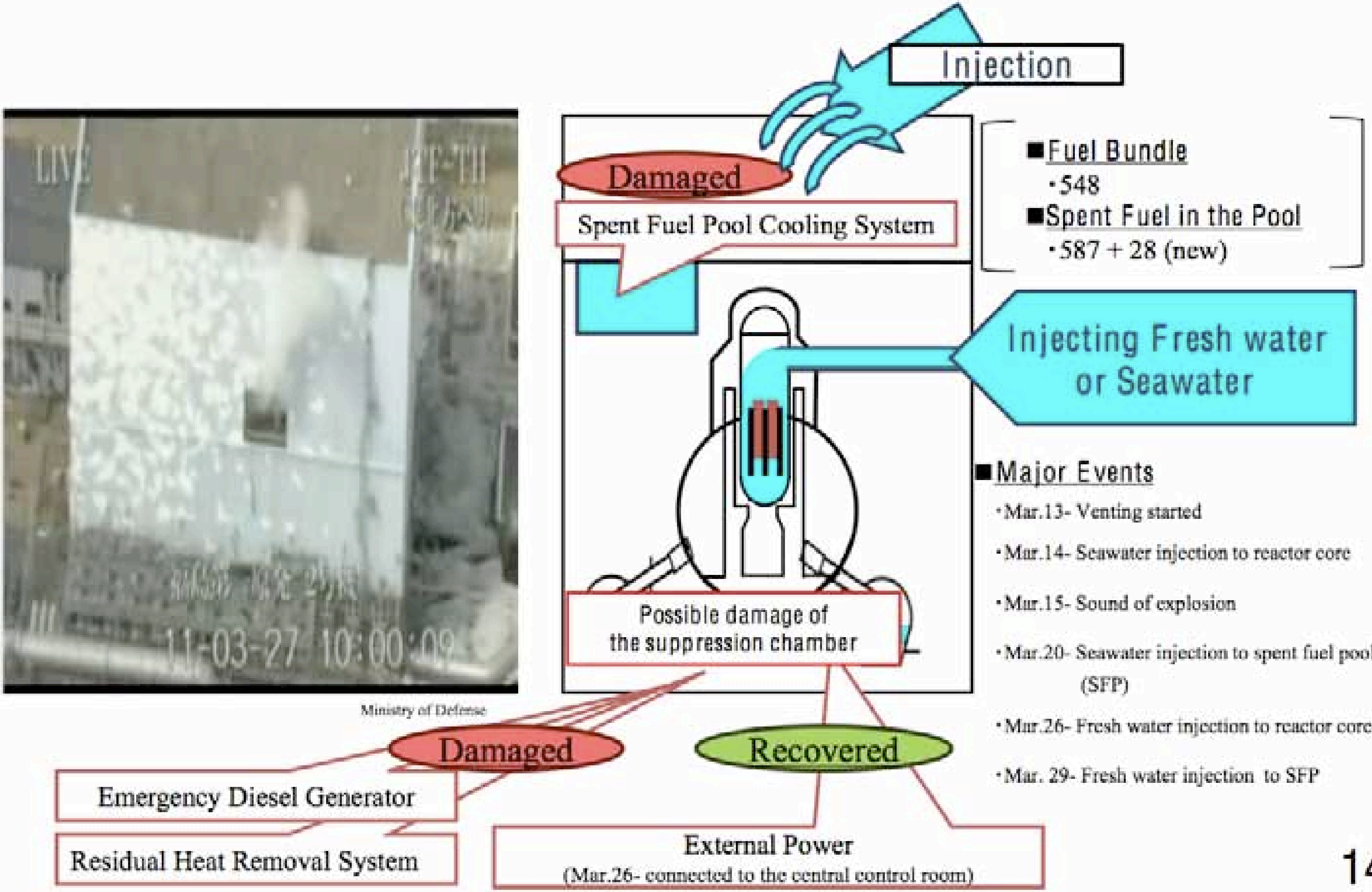
- Reactor Scram: 04:00 3/28/79
- Core melt and relocation: ~ 05:00 – 07:30 3/28/79
- Hydrogen Deflagration: 13:00 3/28/79
- Recirculation  Cooling: Late 3/28/79
- Phased Water Processing: 1979-1993
- Containment Venting: July 1980
- Containment Entry: July 1980
- Reactor Head removed and core melt found: July 1984
- Start Defuel: October 1985
- Shipping Spent Fuel: 1988-1990
- Finish Defuel: Jan 1990
- Evaporate ~2M gallons Processed Water: 1991-93
- Cost: ~$2 Billion
- **F1 - Water Decon. and Cost at least 10 times larger**

# Unit #1 Situation

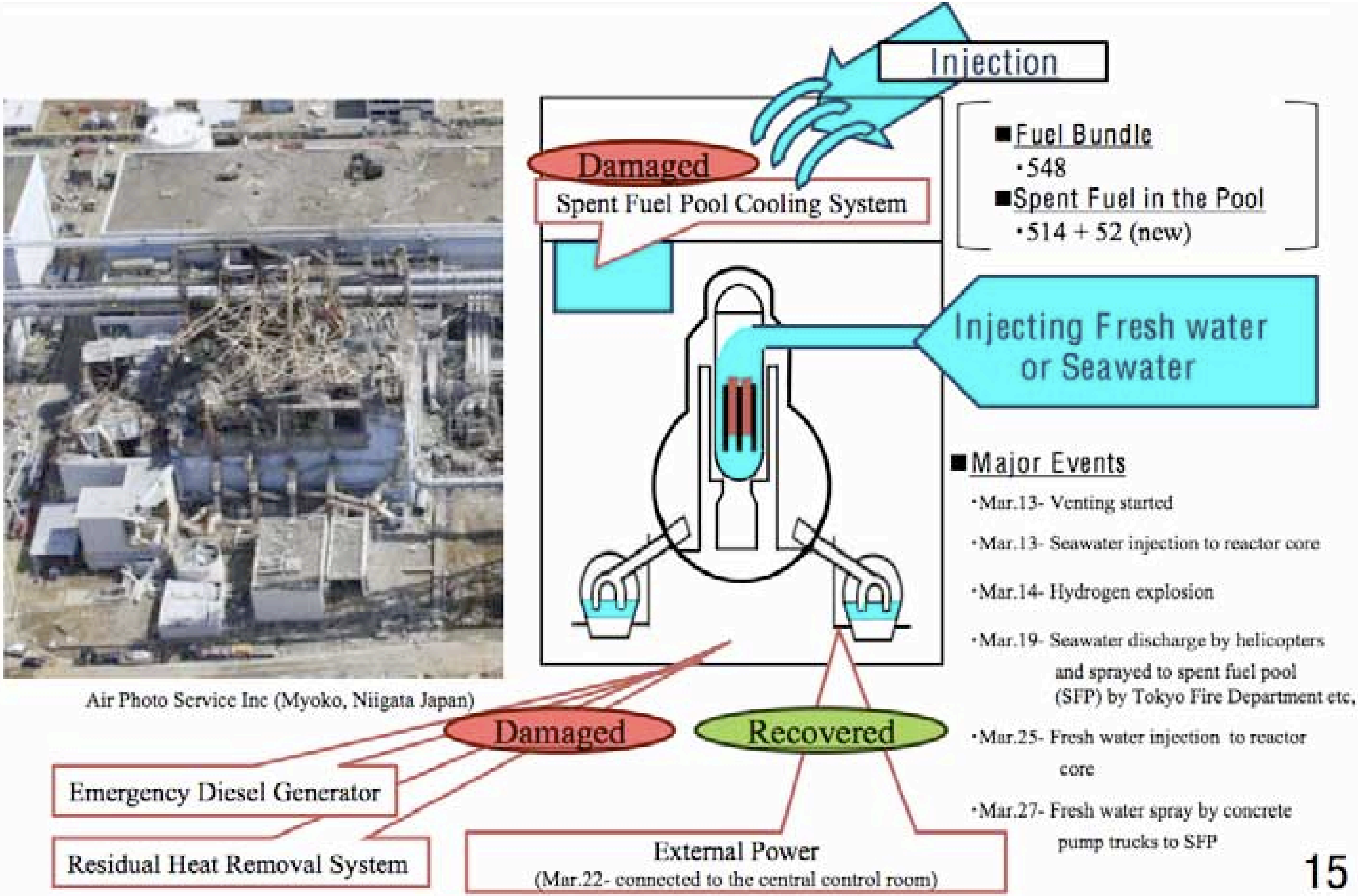

TEPCO



# Unit #2 Situation

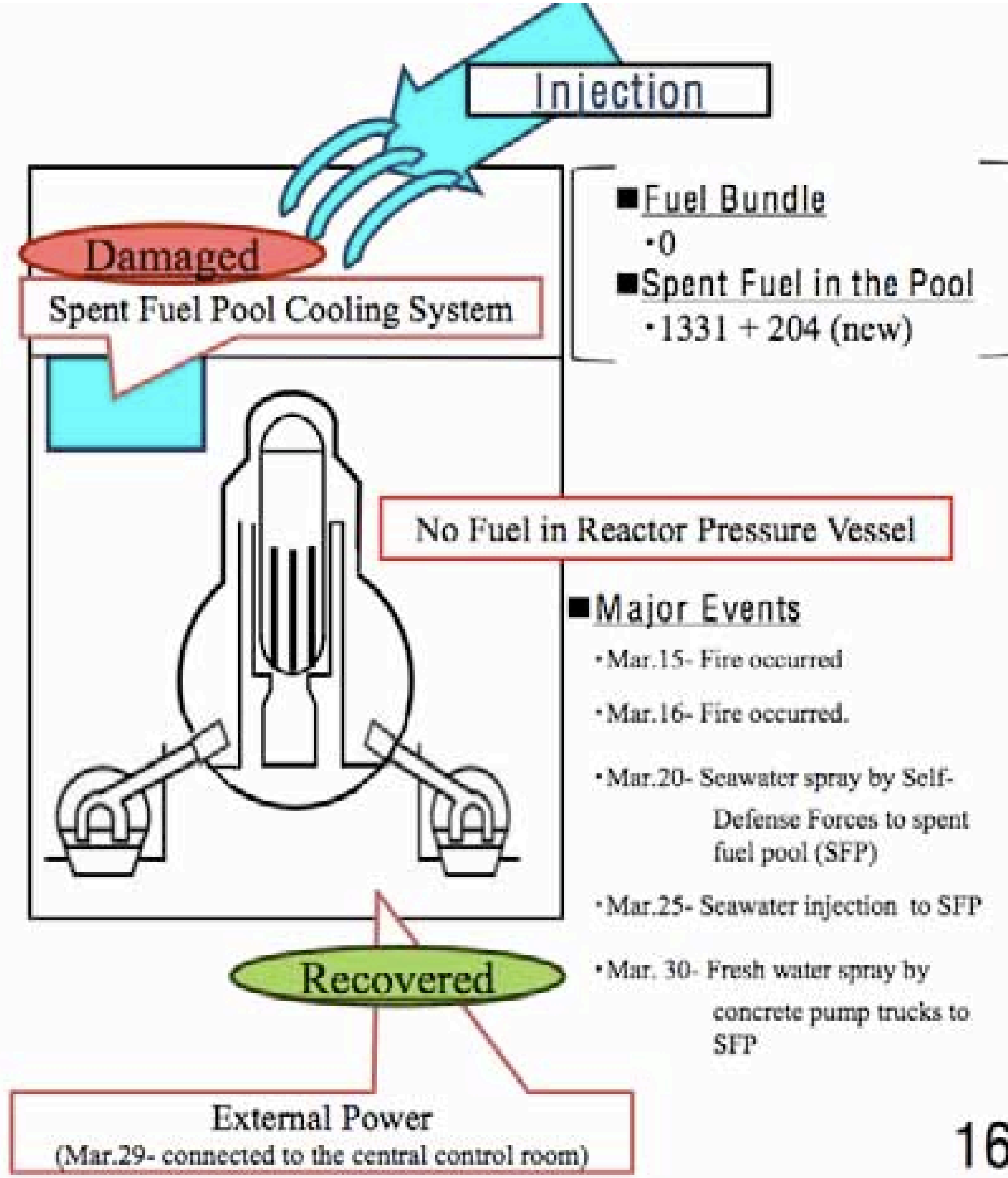


# Unit #3 Situation

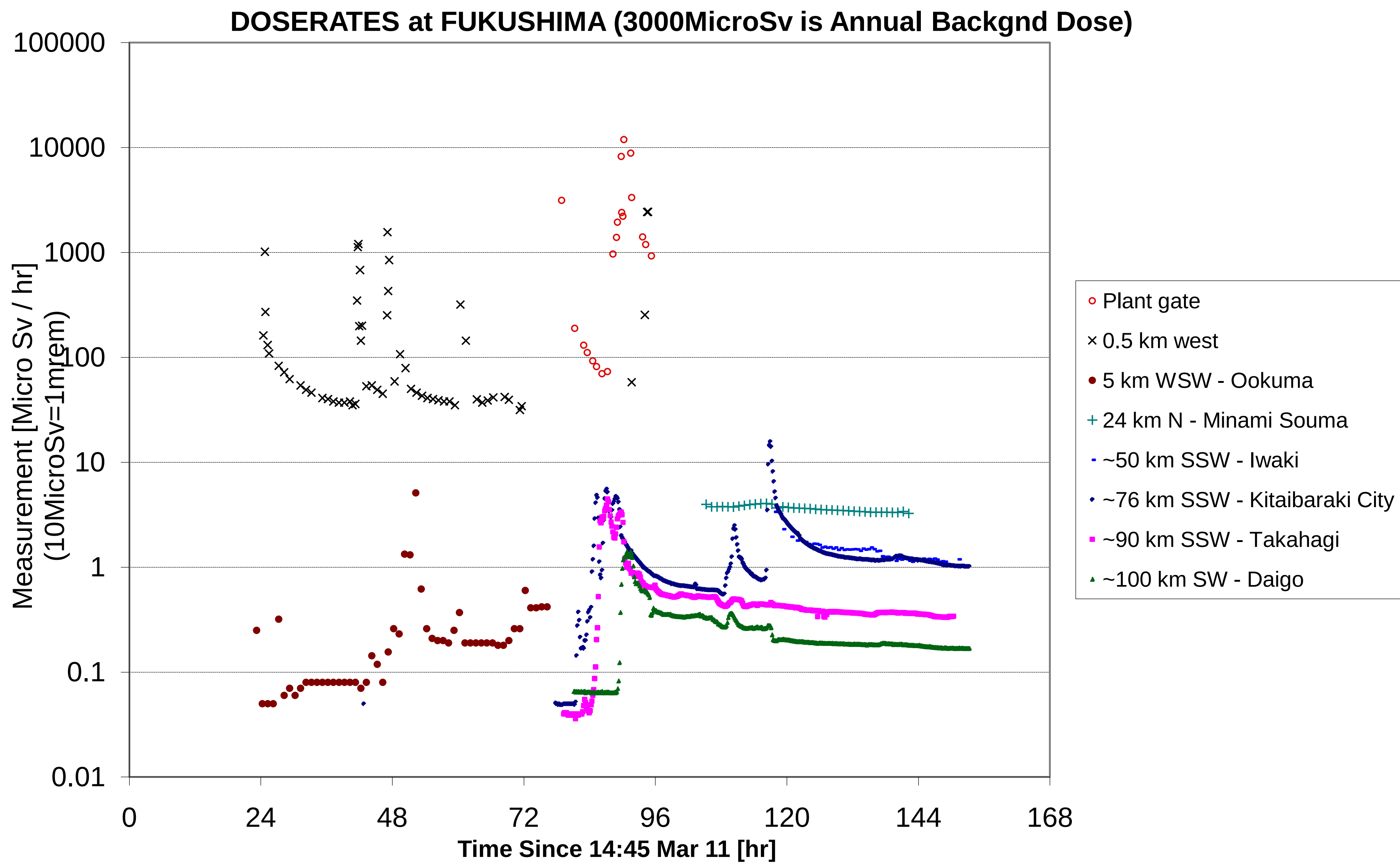


# Unit #4 Situation

Air Photo Service Inc (Myoko, Niigata Japan)



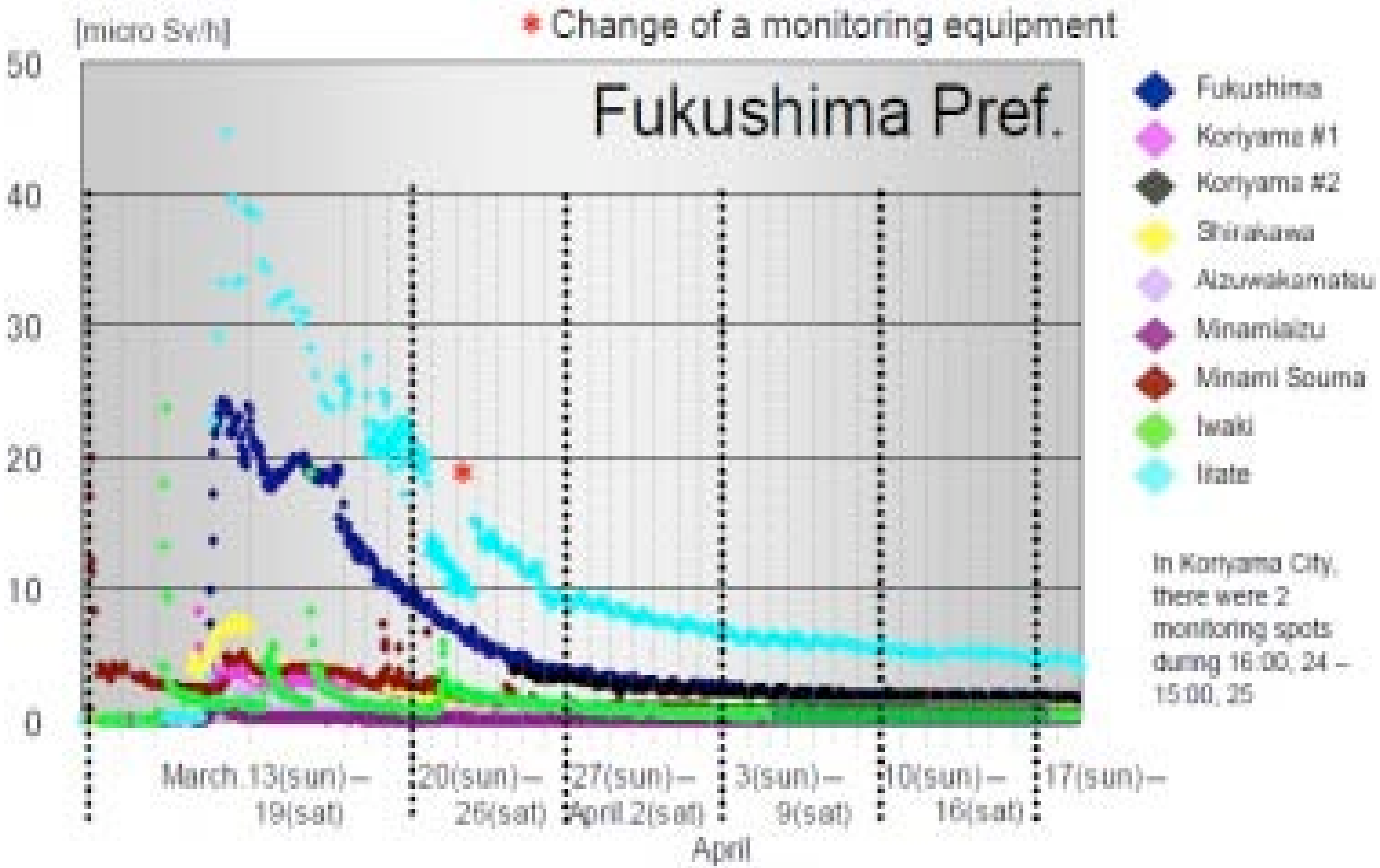
# Dose History at Selected Locations






http://www.mext.go.jp/english/radioactivity_level/detail/1303986.htm

# Dose Comparison History



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