The Japanese Radiological Event at Fukushima Plant 1 (Daiichi)

Joint Meeting of the SFBAC AAPM & NCC HPS, H’s Lordships, Berkeley Marina, Berkeley, CA

April 14, 2011

Michael P. Grissom
Health Physicist

Fukushima Daiichi Unit 4 (032411)
Objectives

- Set the stage regarding the two-prong natural disasters: earthquake and tsunami

- Sequence the events at Units 1-6 at Daiichi and place in perspective with the other significant reactor events in the last 60 years

- Discuss the known radiological levels encountered on site, throughout the Japanese home islands, and in Hawaii and North America

- A bit on the public health consequences based on events as close to the meeting date as practicable
There have been 100s of earthquakes since the force magnitude 9 great quake on 3/11/11.
Pacific Plate & Asian Plate Subduction Zone

Peak Ground Acceleration (m/s²) with 10% Probability of Exceedance in 50 Years
The Great 9 Quake and Aftershocks to 4/12/11
Earthquakes Not New for Japan Latest >5 on 4/13/11
More Than 140,000 Still Displaced 4/13/11

It's cold and wet
camping outdoors
aftershocks multiplying
the misery

(Yasuharu You, Buddis Monk of Shin sect after Niigata earthquake October 2004)

Day of disaster
I can never forget
the cold and wet

(Yasuharu You, Buddhist Monk of Shin sect this disaster)
Minutes Later
Tsunami

The Asian Plate rebounded about 3 feet causing a wave of that size to cross the Pacific eastward to Hawaii and beyond. However, pressure gauges on the sea floor West of the 9 epicenter measured more than 5 feet of sea floor displacement. Waves reflecting off the coastline of Honshu or funneled into inlets resulted in tsunamis coming ashore that were much higher: A 46-foot wave was seen coming over the Fukushima Daiichi anti-tsunami seawall (16 feet).
The big tsunami scattering as far as here, a cloud of seabirds, boats, cars, houses and people in the flow of the western wind.

(Kazuo Oike - seismologist and former President Kyoto University)
Situation Muddled Due to Road, Rail and Shipping Disruptions

Mother’s pain
into the spring sea
her last sleep

(Murasaki Sagano whose mother died 5 days post tsunami)

Nearly entire villages were swept back out to sea by the receding tsunami waters. The Pacific Ocean East of Honshu became a great mass of floating debris: homes, animals, trees, bodies, cars, boats, trains, and more that created significant shipping hazards and impeded recovery efforts to save survivors (the Japanese Coast Guard saved one man on the roof of his house 3 days later and 10 miles out to sea – but his wife perished).

mother’s body remains buried in Onagawacho, Miyagi Prefecture 031711
Debris at Sea

Basho’s road throughout Tohoku hope remains

(Stephen DeGuire trek in post-disaster region)
Fires, Flooding and Aftershocks Added to the Misery

In the confusion and disarray during the first few hours after the great quake and tsunami, many reporting errors surfaced in the media. This famous image was shown with the caption “Fukushima Workers Evacuated From Nuclear Plant.” In fact, it was a petroleum fire at an oil refinery but many in the world press thought it looked like a nuclear plant. The Japanese had no need for erroneous or misleading reporting, and it contributed to the shock of the moment.

About the nuclear power plant
too much detail I hear such unhappiness

(Yoshikatsu Kurota in Asahi 3/24/11)
# Great Earthquakes Comparison

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Japanese Nuclear Plants
Daiichi’s Nuclear Facilities
GE Hitachi BWRs

Boiling Water Reactor
In the event of an explosion, such as from a hydrogen gas blast due to a loss of coolant accident (LOCA), the Containment Building was designed to come apart without significant damage to the much stronger built Primary Containment Vessel (PCV).

A bad practice for the very old GE BWR IIs at Daiichi (essentially 1960s technology commissioned in the early 1970s) was the ‘perching’ of the spent fuel pools on top of the PCV.
Fukushima Daiichi
Before the Quake/Tsunami
Fukushima Daiichi
After the Quake/Tsunami
The Site Before Disaster

- Unit 3
- Unit 4
- Common Turbine Bldg
- South Outflow
- Unit 5
- Unit 6
- Diesels Water Systems
- 16’ Tsunami Wall
- Unit 2
- Unit 1

Tsunami 031111

N
Daiichi Relation to the Earthquake/Tsunami

Crisis at Fukushima 1
Government warns Tuesday of harmful radiation levels near power plant

Epicentre: 9.0-magnitude quake Friday

30km People urged to stay indoors
20km Exclusion zone

Source: USGS/World-nuclear.org
Situation Near Plant

body onto truck Ishinomaki Japan 031811

prefectural road in Satte, Saitama Prefecture 031111
1. Current Situation

Overall, the situation at the Fukushima Daiichi plant remains very serious, but there are early signs of recovery in some functions such as electrical power and instrumentation.

**Provisional INES Level 7 Rating**

The International Atomic Energy Agency (IAEA) can confirm that the Nuclear and Industrial Safety Agency (NISA) has submitted a provisional International Nuclear and Radiological Event Scale (INES) Level 7 rating for the accident at the Fukushima Daiichi nuclear power plant. This new provisional rating considers the accidents that occurred at **Units 1, 2 and 3** as a single event on INES and uses estimated total release to the atmosphere as a justification. Previously, separate provisional INES Level 5 ratings had been applied for **Units 1, 2 and 3**.

Japanese authorities notified the IAEA in advance of the public announcement and the formal submission of the new provisional rating.

The provisional rating was determined by NISA after it received the results of the analysis conducted by the Japan Nuclear Energy Safety Organization (JNES). NISA then applied the INES assessment methodology to calculate the total estimated release in terms of radiological equivalence to I-131. Based on this provisional assessment, NISA concluded that the accident would be provisionally rated INES Level 7 as per the definition below, taken from the INES User’s Manual, 2008 Edition (http://www-pub.iaea.org/MTCD/publications/PDF/INES-2009_web.pdf) [pdf]:

Reactor Accidents Comparison

The world’s three worst nuclear accidents

Three Mile Island | Chernobyl | Fukushima

TMI = 5
Chernobyl = 7
Fukushima = 7

INES Ratings
Sequence of Events at Units 1-6 at Daiichi

it's safe, but
they say over and over
that's worrisome

(Tadashi Nishimura’s lament from the Asahi)
Day 1 Earthquake (14:46 JST)

- Emergency Core Cooling Systems
  1) Residual Heat Removal System
  2) Low-Pressure Core Spray (for LOCA)
  3) High-Pressure Core Injection (for LOCA)
  4) Reactor Core isolation cooling (Unit 2,3 [BWR4])
  5) Isolation Condenser (Unit 1 [BWR3])
  6) Borating System

11.3.2011 14:46 - Earthquake
- Magnitude 9
- Power grid in northern Japan fails
- Reactors itself are mainly undamaged

SCRAM
- Power generation due to Fission of Uranium stops
- Heat generation due to radioactive Decay of Fission Products
  - After Scram ~6%
  - After 1 Day ~1%
  - After 5 Days ~0.5%

areva_japan_accident_20110324

The Fukushima Daiichi Incident – Dr. Matthias Braun - March 31, 2011
Day 1 Earthquake
(Emergency Diesels Running)

- Containment Isolation
  - Closing of all non-safety related penetrations of the containment
  - Cuts off Machine hall
  - Due to successful containment isolation, a large early release of fission products is highly unlikely

- Diesel generators start
  - Emergency Core cooling systems are supplied

- Plant is in a stable safe state
Day 1 Tsunami (15:01 JST)

- 11.3. 15:01(?) Tsunami hits plant
  - Plant Design for Tsunami height of up to 5.7-6.5m
  - Actual Tsunami height 7-11m
  - Flooding of:
    - Diesel and/or
    - Switchgear building and/or
    - Fuel Tanks and/or
    - Essential service water buildings

- 11.3. 15:41 Station Blackout
  - Common cause failure of the power supply
  - Only Batteries are still available
  - Failure of all but one Emergency core cooling system
Day 1 Tsunami (LOCA Begins)

**Fukushima I - Unit 1**
- Isolation Condenser
  - Steam enters heat exchanger
  - Condensate drains back to RPV
  - Secondary steam released from plant
- Need Pumps for Water supply
- Can't replace water in Reactor

**Fukushima I Unit 2 & 3**
- Reactor Core Isolation Pump
  - Steam from Reactor drives Turbine
  - Steam gets condensed in Wet-Well
  - Turbine drives a Pump, pumping Water from the Wet-Well in reactor
- Necessary:
  - Battery power
  - Wet-Well Temperature < 100°C
- No heat removal from the buildings
Day 1 LOCA (Heat Crisis Starts)

- 11.3. 16:36 in Unit 1
  - Isolation condenser stops
  - Tank empty(?)

- 13.3. 2:44 in Unit 3
  - Reactor Isolation pump stops
  - Batteries empty

- 14.3. 13:25 in Unit 2
  - Reactor Isolation pump stops
  - Pump failure

- Consecutively, all reactors are cut off from any kind of heat removal
Day 1 LOCA (Steam Buildup Drives Down Water Levels)

- ~50% of the core exposed
  - Cladding temperatures rise, but still no significant core damage

- ~2/3 of the core exposed
  - Cladding temperature exceeds ~900°C
  - Ballooning / Breaking of the cladding
  - Release of fission products from the fuel rod gaps

(Measured levels are collapsed level. The actual liquid level lies higher due to the steam bubbles in the liquid)
Day 1 LOCA (Zircalloy Burns)

- ~3/4 of the core exposed
- Cladding exceeds ~1200°C
- Zirconium in the cladding starts to burn under steam atmosphere
- \( \text{Zr} + 2\text{H}_2\text{O} \rightarrow \text{ZrO}_2 + 2\text{H}_2 \)
- Exothermal reaction further heats the core
- Estimated masses hydrogen
  - Unit 1: 300-600kg
  - Unit 2/3: 300-1000kg
- Hydrogen gets pushed via the wet-well and the wet-well vacuum breakers into the dry-well
Day 1 LOCA (Fuel Rods Rubblized)

- **at ~1800°C** [expected Unit 1,2,3]
  - Melting of the Cladding
  - Melting of the steel structures

- **at ~2500°C** [expected Unit 1,2]
  - Breaking of the fuel rods
  - debris bed inside the core

- **at ~2700°C** [maybe Unit 1]
  - Significant melting of Uranium-Zirconium-oxides

- **Restoration of the water supply stops accident in all 3 Units**
  - Unit 1: 12.3. 20:20 (27h w.o. water)
  - Unit 2: 14.3. 20:33 (7h w.o. water)
  - Unit 3: 13.3. 9:38  (7h w.o. water)
Day 1 LOCA (Releases Escalate)

- Release of fission products during melt down
  - Xenon, Cesium, Iodine,…
  - Uranium/Plutonium remain in core
  - Fission products condensate to airborne Aerosols

- Discharge through valves into water of the condensation chamber
  - Pool scrubbing binds a fraction of Aerosols in the water

- Xenon and remaining aerosols enter the Dry-Well
  - Deposition of aerosols on surfaces further decontaminates air
Days 2-3 LOCA (Venting of Containment Buildings)

- **Containment**
  - Last barrier between Fission Products and Environment
  - Wall thickness ~3cm
  - Design Pressure 4-5bar

- **Actual pressure up to 8 bars**
  - Normal inert gas filling (Nitrogen)
  - Hydrogen from core oxidation
  - Boiling condensation chamber (like a pressure cooker)

- **First depressurization of the containment**
  - Unit 1: 12.3. 4:00
  - Unit 2: 13.3 00:00
  - Unit 3: 13.3. 8.41
Days 2-3 LOCA (Hydrogen Buildup Escalates)

Positive und negative Aspects of depressurizing the containment

- Removes Energy from the Reactor building (only way left)
- Reducing the pressure to ~4 bar
- Release of small amounts of Aerosols (Iodine, Cesium...)
- Release of all noble gases
- Release of Hydrogen

Release of unfiltered venting?

- Gas is released into the reactor service floor
  - Hydrogen is flammable
Days 2-3 LOCA (Units 1 and 3 Hydrogen Explosions)

Unit 1 and 3
- Hydrogen burn inside the reactor service floor
- Destruction of the steel-frame roof
- Reinforced concrete reactor building seems undamaged
- Spectacular but minor safety relevant
Days 3+ LOCA (Unit 2 “Muffled” Explosion)

Unit 2
- Probably Hydrogen leakage of the condensation chamber (actual pressure exceeds design pressure)
- Burn inside the reactor building in proximity to the wet-well
- Damage to the condensation chamber
- Uncontrolled release of
  - Gas
  - Highly contaminated water
  - Aerosols of fission products
- Temporal evacuation of the plant
- High local dose rates on the plant site due to wreckage hinder further recovery work
Reactors Status 3/31/11

- Current status of the Reactors
  - Core Damage in Unit 1, 2, 3
  - Building damage due to various burns Unit 1-4
  - Reactor pressure vessels flooded in all Units with mobile pumps
  - At least containment in Unit 1 flooded

- Further cooling of the Reactors
  - Unit 1: by Isolation Condensers
  - Unit 2&3: by releasing steam

- Only small further releases of fission products can be expected from Unit 2 and 3
Radiological Levels
Dr. Braun’s Assessment

- Not Chernobyl-like

- Directly on the plant site
  - Before Explosion in Unit 2
    - Below 2mSv/h
    - Mainly due to released radioactive noble gases
    - Measuring posts on west side. Maybe too small values measured due to wind
  - After Explosion in Unit 2 (Damage of the Containment)
    - Temporal peak values 12mSv/h (Origins not entirely clear)
    - Local peak values on site up to 400mSv/h (wreckage / Wet-Well inventory)
    - Currently stable dose on site at 5mSv/h
    - Inside the buildings a lot more
  - Limiting time of exposure of the workers necessary
Reactors Status 4/13/11

- Dr. Braun’s assessment of the Units 1-3 Reactors still applies
- Still difficulties keeping the remaining fuel under water
- The spent fuel pools eventually went through the same process at Units 1-4 (“going dry”) but a much higher yield of radionuclides to the environmental
- TEPCO: “Very gradual improvement”
- Units 5 and 6 appear to be in steady cool down but they have had periodic temperature/pressure increases prior to off-site power being restored
- **Status:** Safe cool down has not been achieved to date – dispersal of radionuclides to the environment by air and water continues
- **Decay Time is our friend!**
Radiological Releases Daiichi
Site 3/11-22/11 Unit 2

Before Containment Damage in Unit 2
After Containment Damage in Unit 2

uSv/h

12:00 AM 12:00 AM 12:00 AM 12:00 AM 12:00 AM 12:00 AM 12:00 AM 12:00 AM 12:00 AM 12:00 AM 12:00 AM 12:00 AM

Main Gate
north of Main Building
west Gate
Radiological Releases Daiichi Site
3/11-22/11 Contaminated Debris

Before Containment Damage in Unit 2

After Containment Damage in Unit 2

Increasing Background due to on-site deposited radionuclide
Fukushima Plant 1 032011 Units
1 thru 3 steam
Fukushima Plant 1 032011 Units 1 thru 4

Earthquake Damage in Concrete
Fukushima Plant 1 032411 Unit 3 Fire Engines

Radiation Levels for Tokyo, Chiba, Saitama, Ibaraki

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Saitama Prefecture Radiation Levels

Fukushima Plant 1 032411
Debris
CORRECTION: UPDATED

Please note the addition of "hundreds of thousands" in the second and sixth paragraphs Radiation Monitors Continue to Confirm That No Radiation Levels of Concern Have Reached the United States

Release date: 03/22/2011
Contact Information: EPA Press Office press@epa.gov

WASHINGTON — During a detailed analysis of four west coast RadNet air monitor filters, the U.S. Environmental Protection Agency (EPA) identified trace amounts of radioactive iodine, cesium, and tellurium consistent with the Japanese nuclear incident. These levels are consistent with the levels found by a Department of Energy monitor last week and are to be expected in the coming days.

EPA’s samples were captured by three monitors in California and one in Washington State on Friday, March 18 and sent to EPA scientists for detailed laboratory analysis. The data was reviewed over the weekend and the analysis was completed Monday night. The radiation levels detected on the filters from California and Washington monitors are hundreds of thousands to millions of times below levels of concern.

All units are in Picocuries per meter cubed.

- Filter results for Anaheim, Calif. found:
  - Cesium-137: 0.0017
  - Tellurium-132: 0.012
  - Iodine-132: 0.0095
  - Iodine-131: 0.046
- Filter results for Riverside, Calif. found:
  - Cesium-137: 0.00024
  - Tellurium-132: 0.0014
  - Iodine-132: 0.0015
  - Iodine-131: 0.011
- Filter results for Seattle, Wash. found:
  - Cesium-137: 0.00045
  - Tellurium-132: 0.0034
- Iodine-132: 0.0029
- Iodine-131: 0.013

- Filter results for San Francisco, Calif. found:
  - Cesium-137: 0.0013
  - Tellurium-132: 0.0075
  - Iodine-132: 0.0066
  - Iodine-131: 0.068
March 30

- As of 4:30pm (EDT)
  EPA’s RadNet radiation air monitors across the U.S. show typical fluctuations in background radiation levels. The levels detected are far below levels of concern.

- As of 8:30am (EDT)
  EPA’s RadNet radiation air monitors across the U.S. show typical fluctuations in background radiation levels. The levels detected are far below levels of concern.

- JOINT EPA/FDA STATEMENT: Update on Ongoing Monitoring
  
  Release date: 03/30/2011
  Contact Information: EPA Press Office, press@epa.gov / FDA Press Office, fdaopa@fda.hhs.gov

  WASHINGTON — In response to the ongoing situation in Japan, the U.S. Environmental Protection Agency (EPA) has taken steps to increase the level of nationwide monitoring of milk, precipitation, drinking water, and other potential exposure routes.

  EPA conducts radiological monitoring of milk under its RADNET program, while the U.S. Food and Drug Administration has jurisdiction over the safety, labeling and identity of milk and milk products in interstate commerce. States have jurisdiction over those facilities located within their territory.

  Results from a screening sample taken March 25 from Spokane, Wash. detected 0.6 pCi/L of iodine-131, which is more than 5,000 times lower than the Derived Intervention Level set by the U.S. Food and Drug Administration. These types of findings are to be expected in the coming days and are far below levels of public health concern, including for infants and children. Iodine-131 has a very short half-life of approximately eight days, and the level detected in milk and milk products is therefore expected to drop relatively quickly.

  "Radiation is all around us in our daily lives, and these findings are a minuscule amount compared to what people experience every day. For example, a person would be exposed to low levels of radiation on a round trip cross country flight, watching television, and even from construction materials," said Patricia Hansen, an FDA senior scientist.

  EPA's recommendation to state and local governments is to continue to coordinate closely with EPA, FDA and CDC. EPA will continue to communicate our nationwide sampling results as they come in.

  EPA: http://www.epa.gov/japan2011

  FDA: http://www.fda.gov/NewsEvents/PublicHealthFocus/ucm247403.htm
Japanese Nuclear Emergency: Radiation Monitoring
April Daily Data Summaries

Last updated on Tuesday, April 12, 2011 at 11:14:36 AM.

April 10 | April 9 | April 8 | April 7 | April 6 | April 5 | April 4 | April 3 | April 2 | April 1

Return to Main Daily Data Summary | View Daily Data Summaries for March

April 10

• As of 8:00am (EDT) EPA’s RadNet radiation air monitors across the U.S. show typical fluctuations in background radiation levels. The levels detected are far below levels of concern.

Today, EPA also released new data for milk, drinking water, precipitation and laboratory air analyses. Results have detected low levels of radioactive material consistent with estimated releases from the damaged nuclear reactors. These detections were expected and the levels detected are far below levels of public-health concern.

April 9

• As of 8:00am (EDT) EPA’s RadNet radiation air monitors across the U.S. show typical fluctuations in background radiation levels. The levels detected are far below levels of concern.

Today, EPA also released new data for milk, drinking water and laboratory air analyses. Results have detected low levels of radioactive material consistent with estimated releases from the damaged nuclear reactors. These detections were expected and the levels detected are far below levels of public-health concern.

To view the most recent sampling and monitoring data, go to http://www.epa.gov/japan2011/rert/radnet-sampling-data.html.
Public Health Consequences

• ???

• Way to early to call since we haven’t:
  – Consolidated releases data for dose assessment
  – Validated the early measurements made
  – Determined the adequacy of the worker’s dosimetry
  – Impact upon local Fukushima Prefecture foodstuffs
  – Impact on Japanese fishing industry in the home waters
  – Possible impact of recovery set-backs due to more large earthquakes at Fukushima Daiichi
Time Adjustments

**UTC**
Coordinated Universal Time

In the United States, Canada or Mexico, to convert to your local time, find your time zone and subtract the number of hours listed.

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March 29, 2011 | By Kenji Hall and Julie Makenen, Los Angeles Times
They sleep with just one blanket apiece anywhere there’s space — in a conference room, in the hallway, near the bathroom. Because deliveries of supplies are limited, they get by on very little food: Breakfast is packages of high-calorie emergency crackers and a small carton of vegetable juice; dinner consists of a small bag of "magic rice" (just add bottled water) and a can of chicken, mackerel or curry. There is no lunch — handing out a noontime meal would be too complicated in the crowded two-story building.
LTJG James Powell, MSC, USN has been the most intimately involved Radiation Health Officer (RHO) in the Fukushima Daiichi event since the very beginning aboard USS RONALD REAGAN (CVN-76). The video of the entire flight deck foamed for decontamination is worth seeing. The ship sailed to the East coast of Honshu Island to assist the Daiichi NPGS, but that was directly in the path of the wind driven airborne radioactivity at the time.
USS RONALD REAGAN
Decontamination
An isolated Japanese hospital thank you photo from US helicopter delivering medical supplies from USS MUSTIN (LT Mannis, MSC, USN RHO, 3/23/11).
7 RHOs were held up in Atsugi awaiting assignment aboard conventional ships. They were transported aboard USS RONALD REAGAN today (3/18/11) via C-2 Greyhound. It appears that 5 of the 7 have been moved to destroyers.
We earnestly make donations but the bank says don't use our system

"Daddy I'm fine" time stopping and restarting email from Tokyo

(Raj Bose in Honolulu upon hearing from son in Japan)

(Kunio Kataoka re Japanese ATM network failures post disaster)

Momoko Onodera evacuation ctr prays husband dead in tsunami 031811
Drones aircraft photos: In these March 24, 2011 aerial photos taken by small unmanned drone and released by AIR PHOTO SERVICE, the crippled Fukushima Dai-ichi nuclear power plant is seen in Okumamachi, Fukushima prefecture, northern Japan. From top to bottom, Unit 1 through Unit 4 (Air Photo Service Co. Ltd., Japan)

http://cryptome.org/eyeball/daiichi-epnp/daiichi-photos.htm

NOVA Japan’s Killer Quake

http://video.pbs.org/video/1863101157

CNN 48 foot tsunami wave hits Daiichi Plant after March 11, 2011 earthquake.


MIT NSE Nuclear Information Hub (http://web.mit.edu/nse/)

http://mit.nse/author/mitnse/

The Fukushima Daiichi Incident – Dr. Matthias Braun - March 31, 2011

Area presentation

Visual Radiation Exposure Chart by Reed Research Reactor staff

http://xkcd.com/radiation/

DOE Releases Monitoring Data – 3/22/11


USGS Earthquake Information (latest earthquakes in Japan)


IAEA Updates

http://www.iaea.org/newscenter/news/tsunamiupdate01.html

Nuclear Energy Institute (NEI) – Latest NEI Update on Japan


Fukushima Daiichi Nuclear Power Station, in Fukushima Prefecture, began operation in 1971 and has six nuclear reactors, the capacity of which is 4,896 MW. The power station is located approximately 250 km (155 miles) north of Tokyo in the towns of Futaba and Ohkuma, facing the Pacific Ocean. The site of the station covers about 3.5 million square meters (865 acres) and the plants are built on solid bedrock.
References 2
Dr. Braun

- Good sources of Information
  - Gesellschaft für Reaktorsicherheit [GRS.de]
    - Up to date
    - Radiological measurements presented
    - German translation of Japanese / English web pages
  - Japan Atomic Industrial Forum [jaif.or.jp/english/]
    - Current Status of the plants
    - Measurement values of the reactors (pressure liquid level)
  - Tokyo Electric Power Company [Tepco.co.jp]
    - Radiological measurements published
    - Status of the recovery work
    - Casualties

Road Clearing Rikuzentakata Iwate Pref 031511