Fukushima ocean impacts

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Umitaka Maru May 2013
Accident at the Fukushima Dai-ichi Nuclear Power Plants

Tsunami 40-50 feet tall

Airborne releases due to overheating, hydrogen explosions & fires

Water used to cool reactors is major pathway for radioactive contaminants to enter ocean

Loss of power, overheating & melt down
Cesium radionuclides in the ocean - what do we know?
- mostly from 1960’s weapons testing but some local sources
- one of major Fukushima radionuclides of concern
- soluble in seawater

$^{137}\text{Cs}$ half-life = 30 years
$^{134}\text{Cs}$ half-life = 2 years
- both isotopes of cesium have same chemical properties

**Fukushima Cs fingerprint**
Because of the shorter half-life of $^{134}\text{Cs}$ and constant ratio of $^{134}\text{Cs}/^{137}\text{Cs} = 1.0$
Various Routes to the Ocean: Boundary Conditions

1. Atmospheric deposition
   - Mid-March (5〜30 P Bq)

2. Direct discharge
   - After late-March (3〜15 P Bq)
   - small source today

3. Through river runoff
   - small and continues

4. Through underground water flow
   - small and continues?

80% Fukushima contamination in ocean
There are still some large uncertainties on the sources and fate of the different radionuclides released to the environment.

\[ P \text{ (peta)} = 10^{15} \]
Comparison of Fukushima to other sources

137Cs release to the sea (PBq)

One year history of cesium-137 in ocean immediately off Fukushima

At nuclear power plant
Ocean Cs levels peak on April 6th
- possible reproductive effects and mortality for marine biota

Levels of concern for seafood
US drinking water limit

Levels prior to March 11

one banana

One banana

Highest ocean levels post Chernobyl

Data from TEPCO

Buesseler et al., 2012

- Fukushima NPP represents unprecedented release of radionuclides to the ocean
- levels decreased rapidly, then leveled off
- remain at >1000 Bq m⁻³ through end 2012
- so reactor site remains a source
- but levels now safe for marine biota & human exposure
- what about seafood?
In April 2011, see both near shore and far field sources of cesium

Cs in ocean at low levels at great distances in April 2011 due to atmospheric source

Higher Cs close to Japan due to direct ocean discharge

Honda et al. 2012
$^{134}\text{Cs}$ varies by 3 orders of magnitude—up to 4000 Bq m$^{-3}$

Kuroshio acts as barrier (if air deposition to south, not very much)

Highest values associated with near shore eddy

$^{134}\text{Cs} \ t_{1/2} = 2 \text{ yr} \ >99.5\% \ \text{soluble}$

_Buesseler et al. PNAS April 2012- data available on line_
Drifters were released off Japan in June 2011
Map shows surface ocean drifter tracks as of July 2012
Provides direct measure of transport times
Note - debris moves faster due to winds
*Rypina et al., 2013*
Cs–137 (2011 MAR 21)

Masamoto et al. JAMSTEC
JCOPE2 Tracer-Run

Cs–137 (2011 APR 30)

<Observed data is assimilated till June 16, 2012>

Masumoto et al JAMTEC

Kurashio current

Ships of Opportunity- Aoyama et al., 2013
Fukushima Cs as a tracer- significant models differences

- Predicted $^{137}$Cs off US varies from 30 to 1-2 Bq m$^{-3}$ in different models
- Little/no vertical data to test

$^{137}$Cs arrival

\[ \text{Rossi et al., DSRI, 2013} \]
Cesium-137 today off Japan (Nov. ‘12)

Power plant >0.3 TBq/month

River water <<1 TBq/month

River sediment 0.8 TBq/month

Seawater 15 TBq (TBq = 10^{12} Bq)

Seafloor 94 TBq

Kanda et al TUMST
Leak from the plant

$^{137}$Cs release in summer 2012
Harbor-water: $2.3 \times 10^6$ m$^3$
Exchange rate: 0.44 day$^{-1}$ (6～19 April 2011)
Average $^{137}$Cs at "Unloading dock":
9.9 Bq L$^{-1}$ (1 April ～30 September 2012)

10 GBq day$^{-1}$  0.30 TBq month$^{-1}$

$^{137}$Cs radioactivity at “Unloading dock” inside the plant harbor

Data source: TEPCO
Japanese Nuclear Plant May Have Been Leaking for Two Years
By HIROKO TABUCHI
Published: July 10, 2013

Increasing groundwater concentrations would increase continued source at NPP site
Reports of >10x increase in GW concentrations

Tritium readings inside port facility
Until April: relatively stable at 100 bq/l
June 21: 1,100 bq/l
July 3: 2,300 bq/l

GW are relatively high are $^{90}$Sr and tritium
$^{137}$Cs/$^{90}$Sr in initial release = 40
$^{137}$Cs/$^{90}$Sr in GW <0.01

TEPCO building containment wall between NPP and ocean & removing Cs (so far) from cooling waters

New concern about $^{90}$Sr in fish
Cs contamination has already led to fisheries closures
Fisheries losses >$10 Billion
What about Fish and cesium accumulation?

Information page from Japanese Ministry of Agriculture, Forestry and Fisheries (MAFF)

Cesium uptake and loss from fish is rapid.

*Radioactive cesium excretes, and thus does not accumulate.
*Concentration in fish depends on that of ambient water.

(Reference: Fundamental physiology of fish, Edit. K. Aida)
What about fish off Japan- where do fish have highest cesium?

- Fisheries closed off Fukushima

Bottom dwelling fish only
Which type of fish off Japan are most contaminated?

- bottom fish & freshwater fish
- still high after 1 year
- variability unpredictable
- 18% of fish reported are above limit

Data source: Japan Fisheries from Buesseler, Science, 2012
How have the trends continued through end 2012?
A closer look at Fukushima bottom fish

Cesium levels are not decreasing as fast as expected

Non steady-state food web model explains some of this (Tateda et al. 2013)

There must be a continued cesium source
- contaminated seafloor
- nuclear power plant site
A closer look at Fukushima bottom fish

Cesium decrease is slower than expected
- 50% in 330 days
- many fish still above legal limits
- highest values to date in Feb. 2013
  740,000 Bq/kg in NPP embayment
What about Fukushima Cs in Sediments?

Significant variability between sites & at any one site/time

No close correlation with distance from NPP

No obvious decrease with time

<1% of total Cs ended up in sediment

still important source for seafloor biota

*Kusakabe et al., BGD, 2013*
Summary of sources and fate of Fukushima Cs in the ocean

Direct ocean discharge 3.5-15 PBq

Atmospheric fallout 12-15 PBq

Rapid offshore transport >99% Cs soluble

FNPP
Rivers

groundwater?

sinking marine snow

seafloor burial ≈ 0.04 PBq?

vertical mixing

remineralization

near bottom sediment flow

Many uncertainties remain about long term fate of cesium & other radionuclides
Lessons learned
Fukushima NPP represents unprecedented release of radionuclides to the ocean off Japan

Many reasons for study-
  Human health- internal/external dose assessments
  Radioecology- marine biota & fish
  Modeling- new ocean tracers & future accidents

Japan is leading studies, but more work is needed than any one lab, or any one country can take on

Confirmation by multiple international and independent labs will build public confidence in Japan (and increase scientific insights)

Studies of fish are not enough- need long term studies of ocean, seafloor, rivers, etc.

Easier to measure Cs than to determine health effects
Nov. ‘12 Tokyo & May ‘13 WHOI
Scientific assessment of Fukushima radionuclides- sources, fate, impacts on marine ecosystems and human health, public policies and communication

Short presentations
Panel Q&A

Center for Marine & Environmental Radioactivity
Mission is to increase our understanding of the sources, fates and consequences of natural and human-made radionuclides in the environment, in particular the ocean
http://www.whoi.edu/CMER
THANKS to many in US, Japan, EU.....