

Fukushima Accident: Radioactive Releases and Potential Dose Consequences

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ANS Annual Meeting

Special Session: The Accident at Fukushima Daiichi—

Preliminary Investigations

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Overview

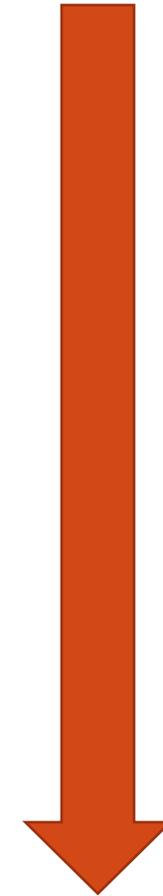
- Radioactive Material Releases
 - Transport and Deposition
 - Dose/Risk Impacts
 - On-site impacts
-
- Comparisons with Chernobyl are problematic, but inevitable

Expected Radioactive Material Releases

- WASH 1400 identified four stages of core material release
 - Gap Release
 - Meltdown Release
 - Vaporization Release
 - Oxidation Release
- Time since shutdown has significant effect
 - Spent fuel pools will not contain short-lived products

Expected Radioactive Material Release

- Noble Gasses (Xe-Kr)
- I
- Cs, Rb
- Te, Sb
- Ba, Sr
- Ru, Mo, Rh, Tc, Co
- Nd, Y, Ce, Pr, La, Nb,
Am, Cm, Pu, Np, Zr



Decreasing
Likelihood of
Release

Observed Radioactive Material Releases

- I-131 – 130-160 PBq (3.5-4.3 MCi)
- Cs-137 – 6.1-15 PBq (165-405 kCi)
 - Chernobyl: 1760 PBq I-131 & 81 PBq Cs-137
- Reports indicate small quantities of Sr and Pu detected outside of plant (3.4-4400 Bq/kg combined Sr-89 & Sr-90 on site)
- Isotopes detected in stagnant water in plant:
 - Cl-38, As-74, Y-91, I-131, Cs-134, Cs-136, Cs-137, La-140
- Te-132 also reported in early monitoring by UCB lab

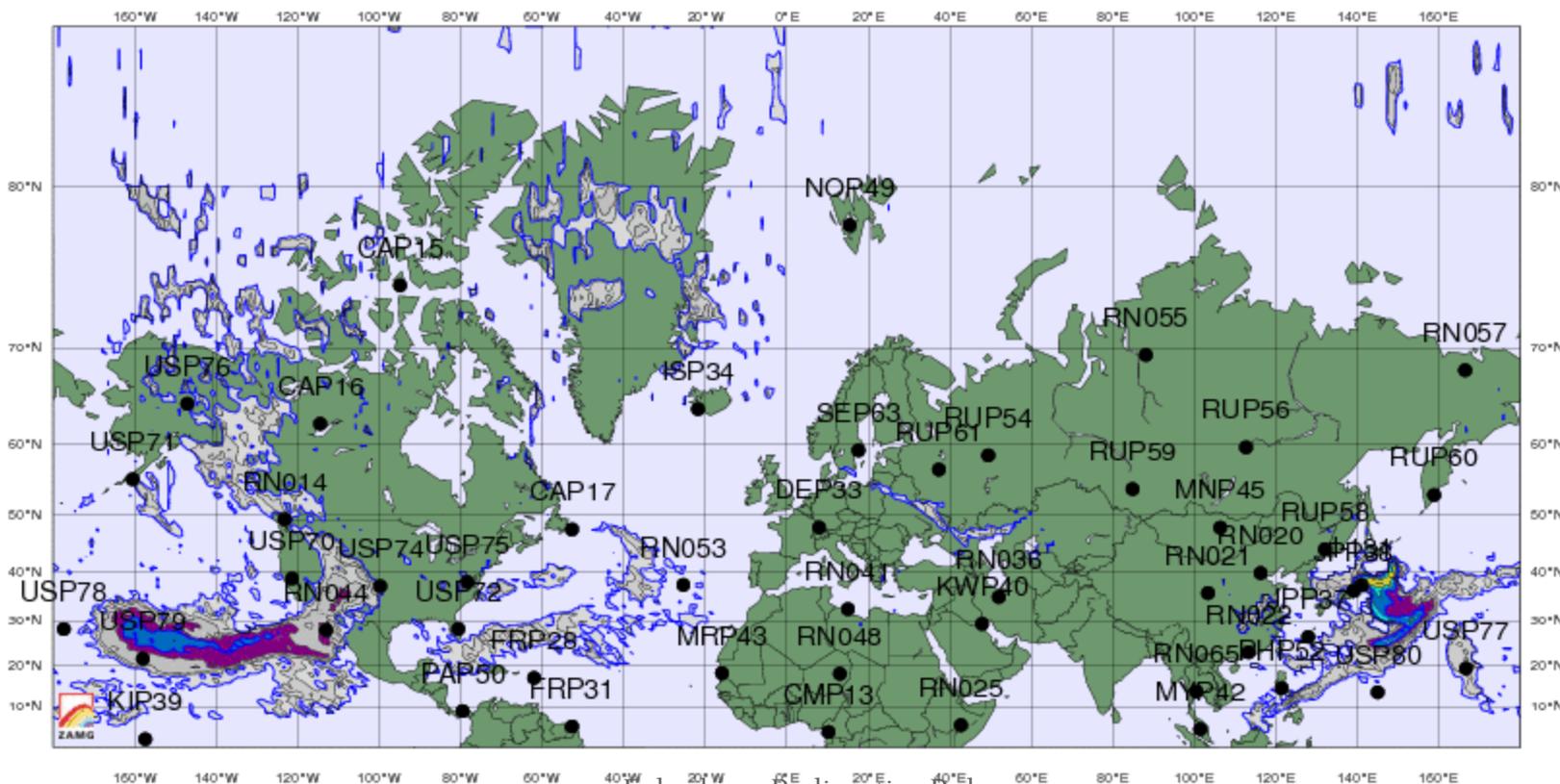
Transport and Deposition of Radioactive Releases

- Iodine-131 detected worldwide
- Cesium-137 & -134 detected over relatively broad areas, including western US
- At this point, transportation and deposition is mostly shown through *models* (not measurements)

Transport and Deposition of Radioactive Releases

- I-131 Transport

AKW_FUKUSHIMA-I-131
20110325-150000
Plume (units m^{-3}), Release: $0.10E+20$ Units



Fukushima Radioactive Releases

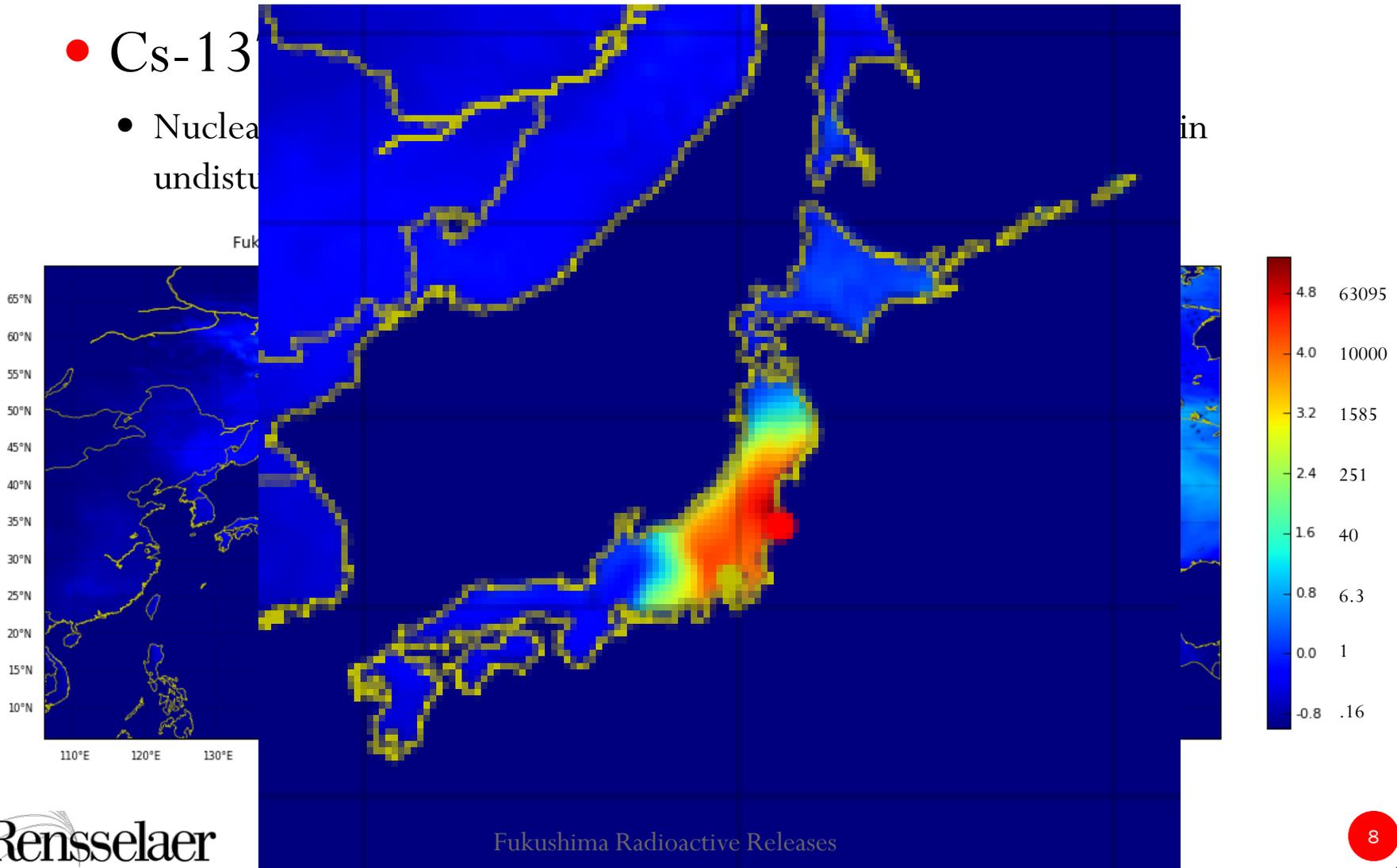


Transport and Deposition of Radioactive Releases

- Cs-137

- Nuclear undisturbed

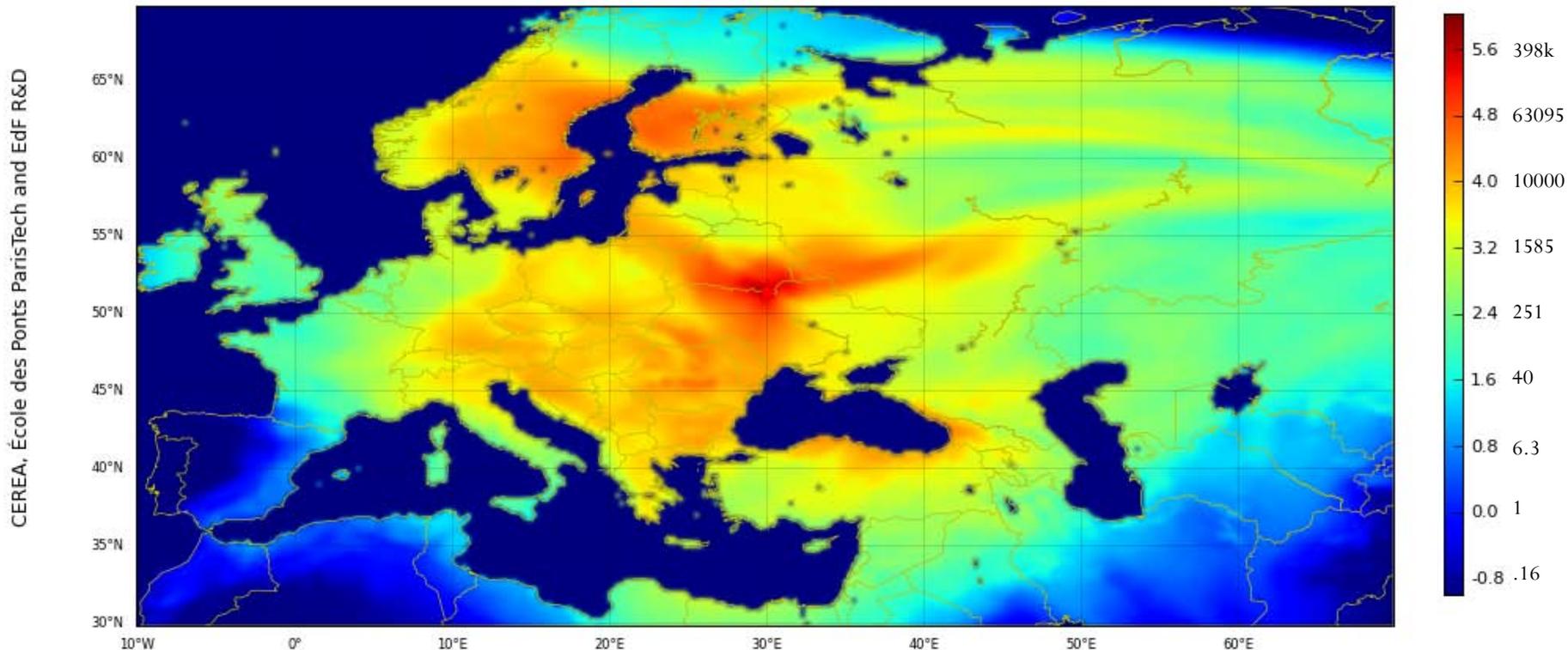
CEREA, Ecole des Ponts ParisTech and EdF R&D



Transport and Deposition of Radioactive Releases

- Cs-137 Deposition

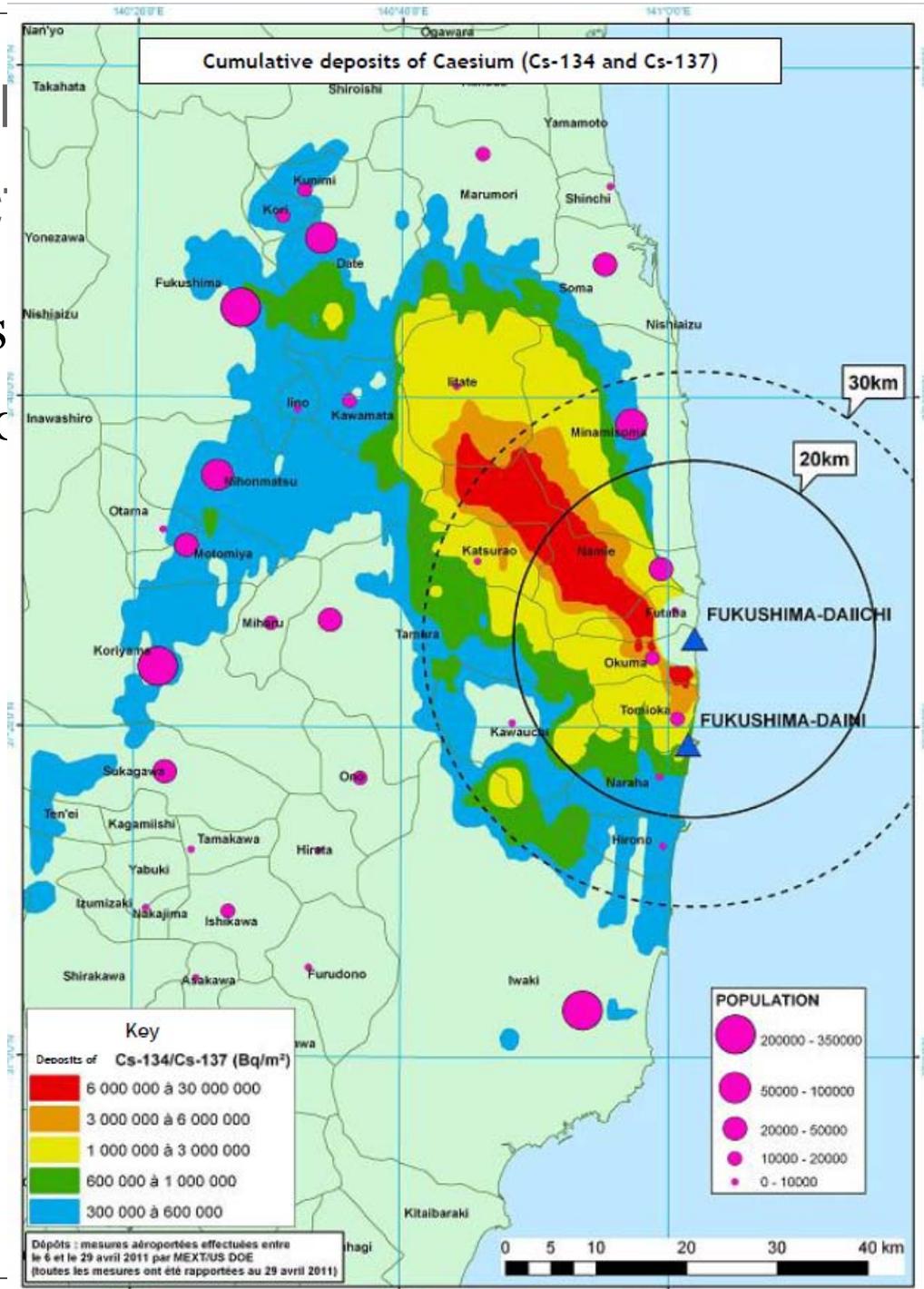
Chernobyl, caesium-137, 1986-05-09 00:00:00, base-10 log of total ground deposition ($Bq.m^{-2}$)



Transport Radioac

- Depos
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the area



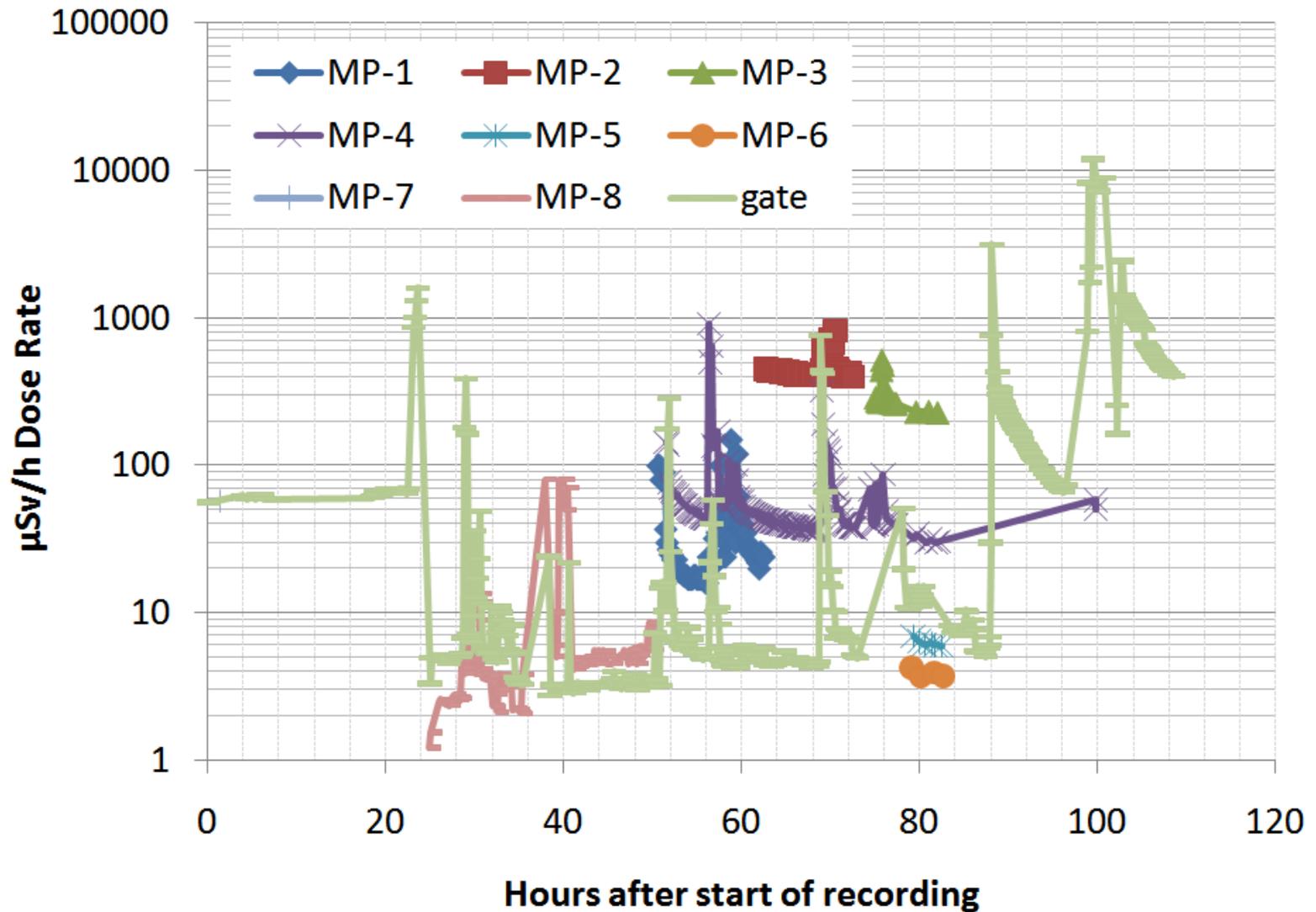
Dose Due to Radioactive Releases

- Air Submersion
 - Instantaneous/transient
- Inhalation
 - Dose commitment
- Ground Irradiation
 - Persistent
- Ingestion
 - Dose commitment

Radioactive Material in Air

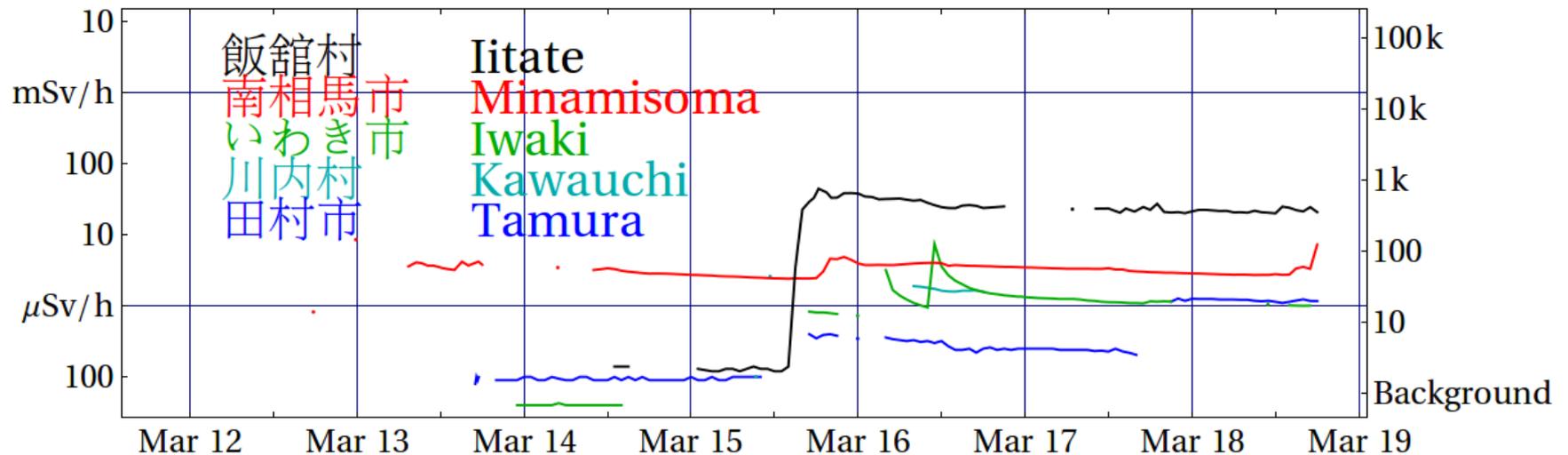
- Early dose measurements dominated by atmospheric submersion
- Dose rate conversions:
 - Cs-137 – $9.6 \times 10^{-11} \frac{Sv}{hr} / \frac{Bq}{m^3}$
 - Cs-134 – $2.5 \times 10^{-10} \frac{Sv}{hr} / \frac{Bq}{m^3}$
 - I-131 – $5.8 \times 10^{-11} \frac{Sv}{hr} / \frac{Bq}{m^3}$

Radioactive Material in Air



Radioactive Material in Air

Radiation at Various Outlying Fukushima Locations (Log Scale)



Radioactive Material in Air

- Dose commitment from breathing contaminated air:
 - Cs-137 – 9.6×10^{-9} Sv/Bq
 - Cs-134 – 1.2×10^{-8} Sv/Bq
 - I-131 – 1.5×10^{-8} Sv/Bq
- Dose commitment per hour is **240** times external exposure rate
 - 1.2 m³/hr breathing rate
 - Cs-137:Cs-134:I-131 at 1:1:16
 - Will decrease over time to ~74x as I-131 decays

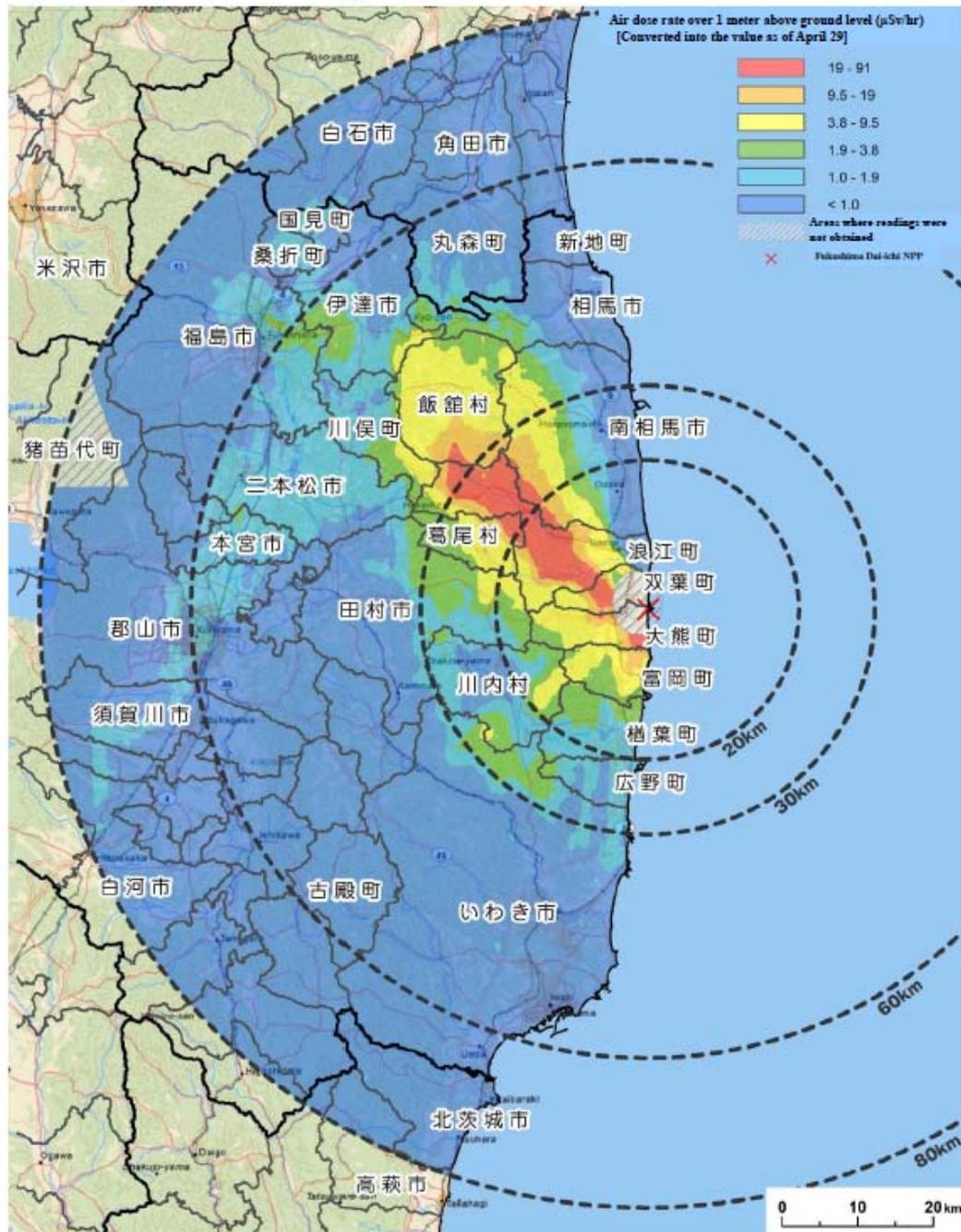
Radioactive Material on Ground

- After plume passes, radiation dose will be dominated by material deposited on ground
- Dose rate conversions:
 - Cs-137 – $1.9 \times 10^{-12} \frac{Sv}{hr} / \frac{Bq}{m^2}$
 - Cs-134 – $5.0 \times 10^{-12} \frac{Sv}{hr} / \frac{Bq}{m^2}$
 - I-131 – $2.5 \times 10^{-12} \frac{Sv}{hr} / \frac{Bq}{m^2}$

(Readings of air dose monitoring inside 80km zone of Fukushima Dai-ichi NPP)

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Radioactive Material on Ground

- Inhalation hazard may be generated by resuspension of deposited material
- Assuming resuspension factor $\sim 10^{-6} \text{ m}^{-1}$, inhalation dose commitment rate $\sim 0.4\%$ of external dose rate (combined Cesium)

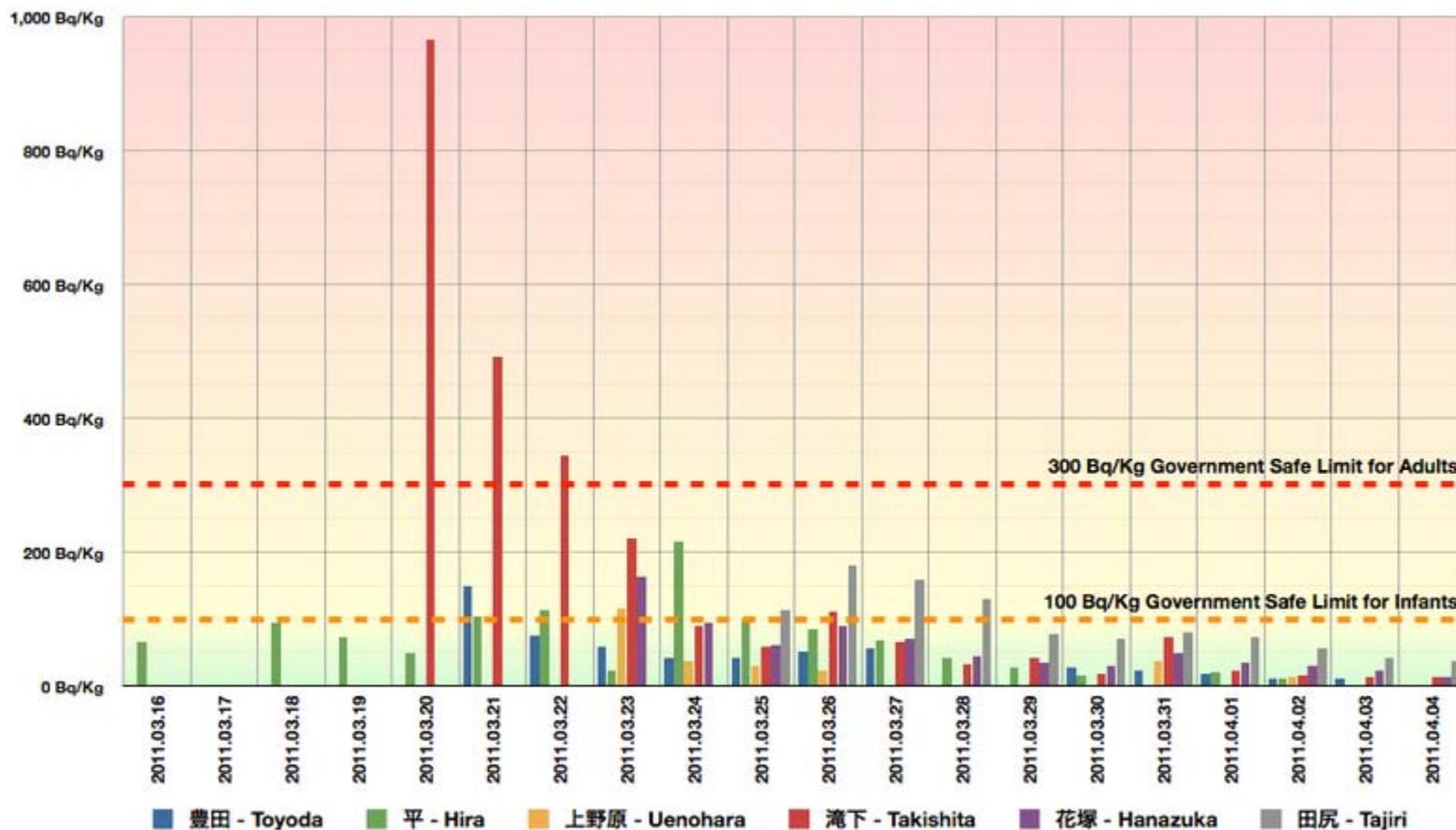
Radioactive Material on Ground

- Material deposited on the ground may enter the food chain and be ingested
 - Cs-137 – 1.4×10^{-8} Sv/Bq
 - Cs-134 – 2.0×10^{-8} Sv/Bq
 - I-131 – 2.4×10^{-8} Sv/Bq

Radioactive Material on Ground

ヨウ素131 福島県浄水場 - Iodine 131 Fukushima Prefecture Water Purification Plant

2011.03.18 ~ 2011.04.04



Data from <http://www.pref.fukushima.jp/j/index.htm>

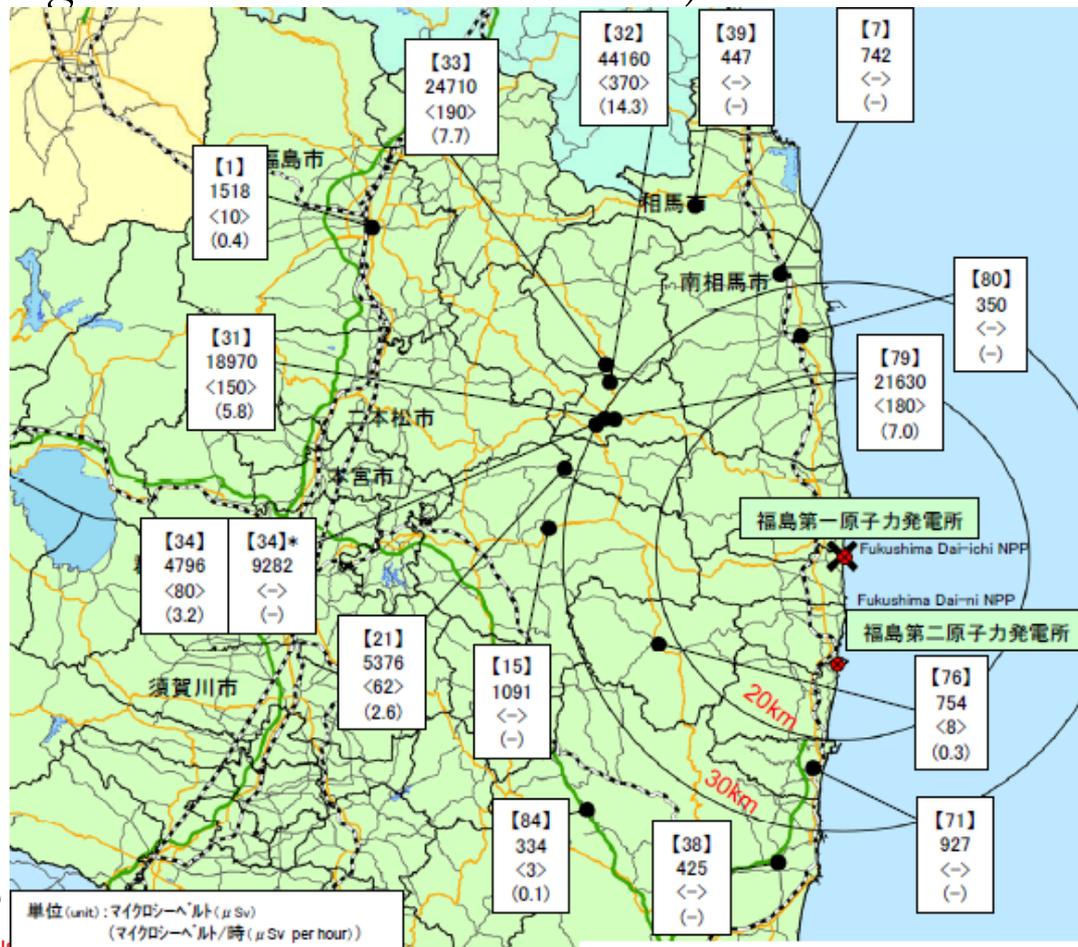
Fukushima Radioactive Releases

Radioactive Material on Ground

- I-131 contamination of varying levels was detected in milk, spinach, and other produce following the accident
- Export and consumption restrictions remain in effect for much of the area

Impacts of Radioactive Releases

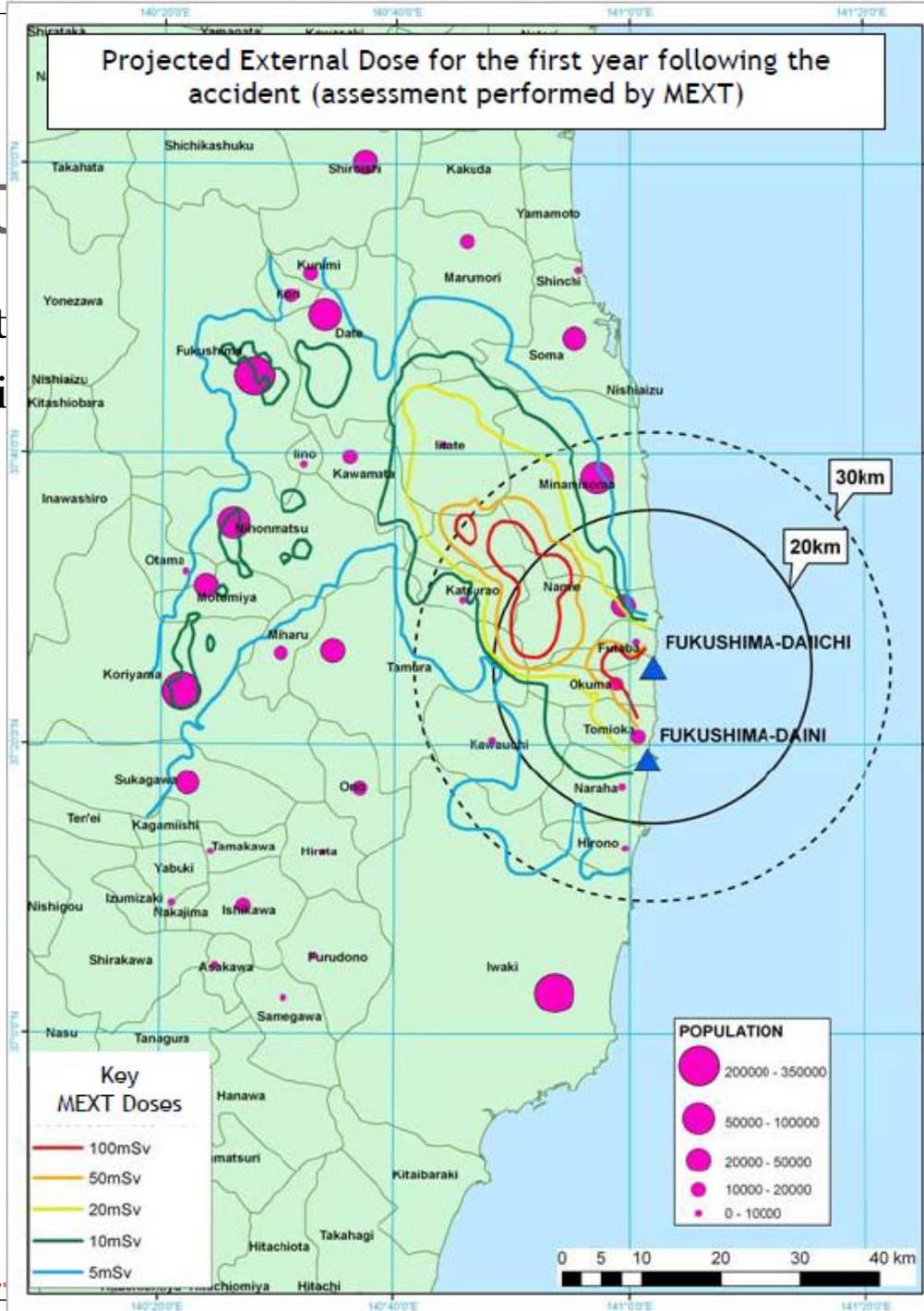
- Measured external integrated dose (MEXT monitoring stations – most begun ~1 week after accident)



Impact

- Projected external dose (not including

Projected External Dose for the first year following the accident (assessment performed by MEXT)



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(not including

Impacts of Radioactive Releases

- Population (outside 20 km zone) affected by radioactive deposition (pre-earthquake census information)

Deposits of caesium (137 + 134) (Source MEXT)	> 300,000 Bq/m ²	> 600,000 Bq/m ²	> 1 million Bq/m ²	> 3 millions Bq/m ²	6 - 30 millions Bq/m ²
External dose 1 st year (16.6 mSv by MBq/m ²)	> 5 mSv	> 10 mSv	> 16 mSv	> 50 mSv	100 - 500 mSv
External dose at 10 years (70 mSv by MBq/m ²)	> 19 mSv	> 38 mSv	> 63 mSv	> 190 mSv	380 - 1,900 mSv
External lifetime dose (70 years) (160 mSv par MBq/m ²)	> 41 mSv	> 82 mSv	> 136 mSv	> 408 mSv	816 - 4,080 mSv
Affected population (excluded the no-entry zone)	292,000	69,400			
		43,000	26,400		
			21,100	3,100	2,200

- Government has set 20 mSv/a limit for occupation, potentially affecting and additional ~20,000 people (sans remediation efforts)

Impacts of Radioactive Releases

- All cumulative dose estimates outside 80 km (50 miles), and much of the area inside that distance, are less than 1 mSv/a
- Collective dose estimates can vary widely based upon assumptions and future evacuation plans, but reasonable current estimates are in the range of 800-1800 person-Sv to the most affected population, and perhaps several times that to the greater surrounding population
 - Chernobyl ~255,000 person-Sv
 - TMI ~20 person-Sv (total)
- At this level, projected increase in cancer mortality would be ~0.001% above the natural rate

Reported Doses to Plant Workers

- As of 6/13

Dose Category (mSv)	External	Internal	Total
>250	0	6	8
200-250	0	3	6
150-200	7	7	21
100-150	17	13	67
50-100	116	100	215
20-50	297	321	417
10-20	527	369	392
<10	2762	1548	1241
Total	3726	2367	2367

Conclusions

- Deaths due to earthquake/tsunami: $\sim 25,000$
- Deaths or serious injuries due to direct radiation exposures: 0
- Cancer deaths due to accumulated radiation exposures: can't be ruled out – conservative risk estimates ~ 100 s cases, against an expected ~ 10 million cases
 - Remediation efforts or further evacuation may be necessary to avoid a sub-population with a significantly higher risk