DOE Role in Fukushima Response

Frank Moore

Aug 10, 2012

Statement of Problem

- Occurred 14:46 March 11, 2011
- Magnitude:9.0 Mw
- Epicenter location: 38° 6''N and 142° 51''E, and 24km in depth
- It is said that the height of tsunami attacked Fukushima NPP was more than 14m

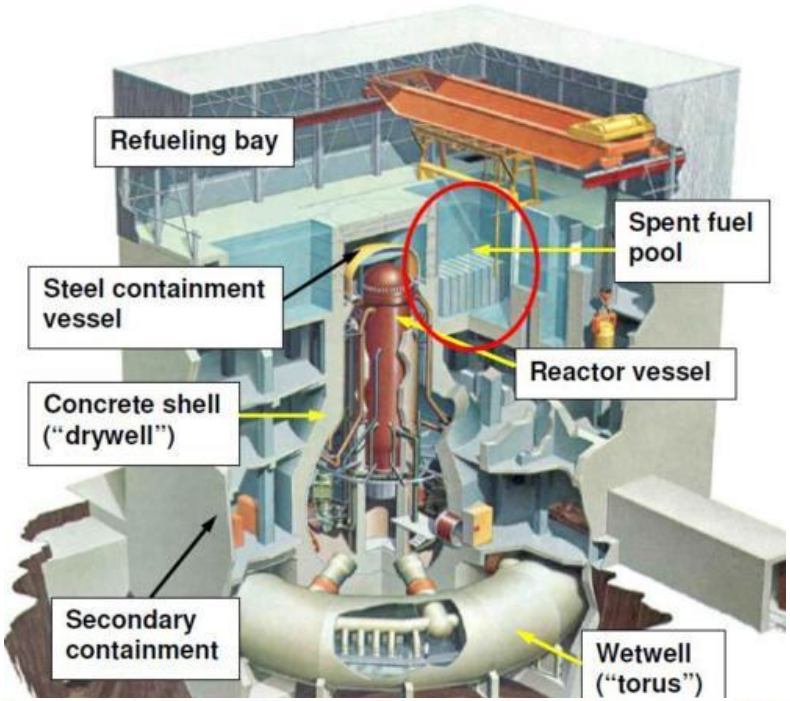
Source: Nuclear and Industrial Safety Agency (NISA)

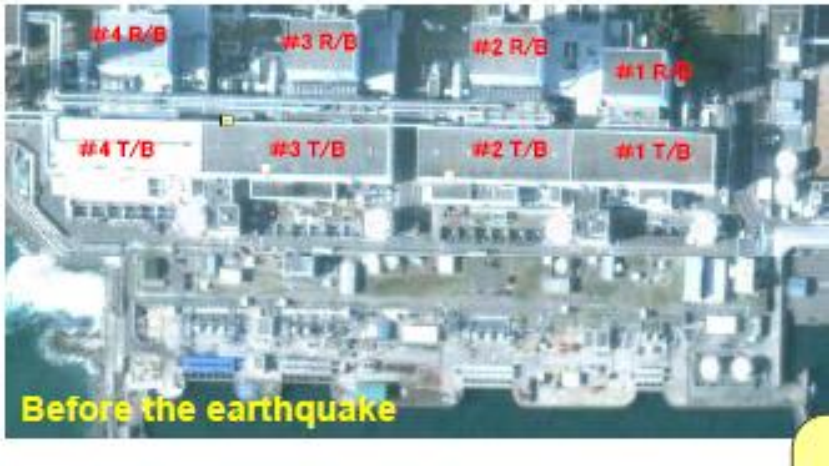
Overview of Fukushima Dai-ichi Nuclear Power Plant

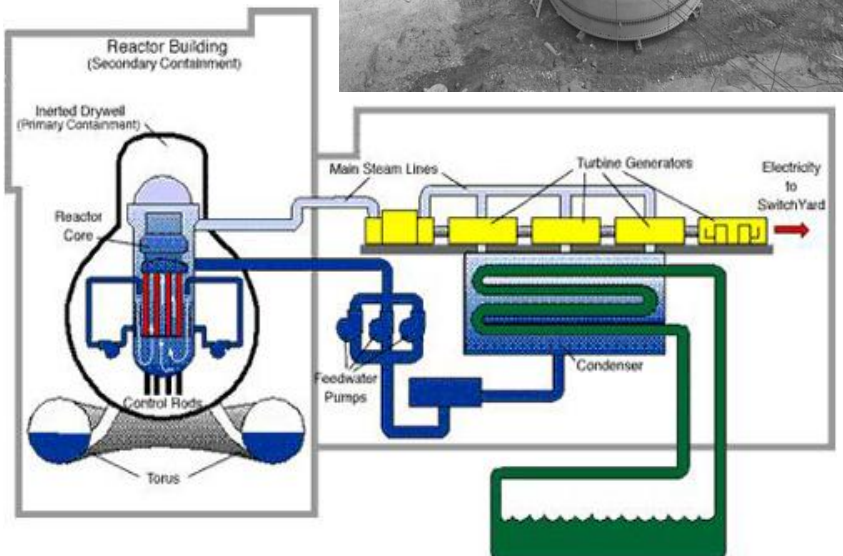
- 6 Boiling Water Reactor (BWR) plants
  - Fuel Type – UO_2 (MOX Unit 3)
  - Output (MWe)
    - Unit 1: 460
    - Unit 2-5: 784
    - Unit 6: 1,100
- Years of commercial operation: ~32-38
- Plant status on March 11
  - Unit 1–3: In operation since Fall 2010
  - Unit 4-6: Refueling Outage

Spent Fuel Pools	1	2	3	4	5	6
# of Spent Fuel Assemblies	292	587	514	1331	946	876
# of New Fuel Assemblies	100	28	52	204	48	64
Water Volume (m^3)	1,020	1,425	1,425	1,425	1,425	1,497

Mark I Boiling Water Reactor (BWR)

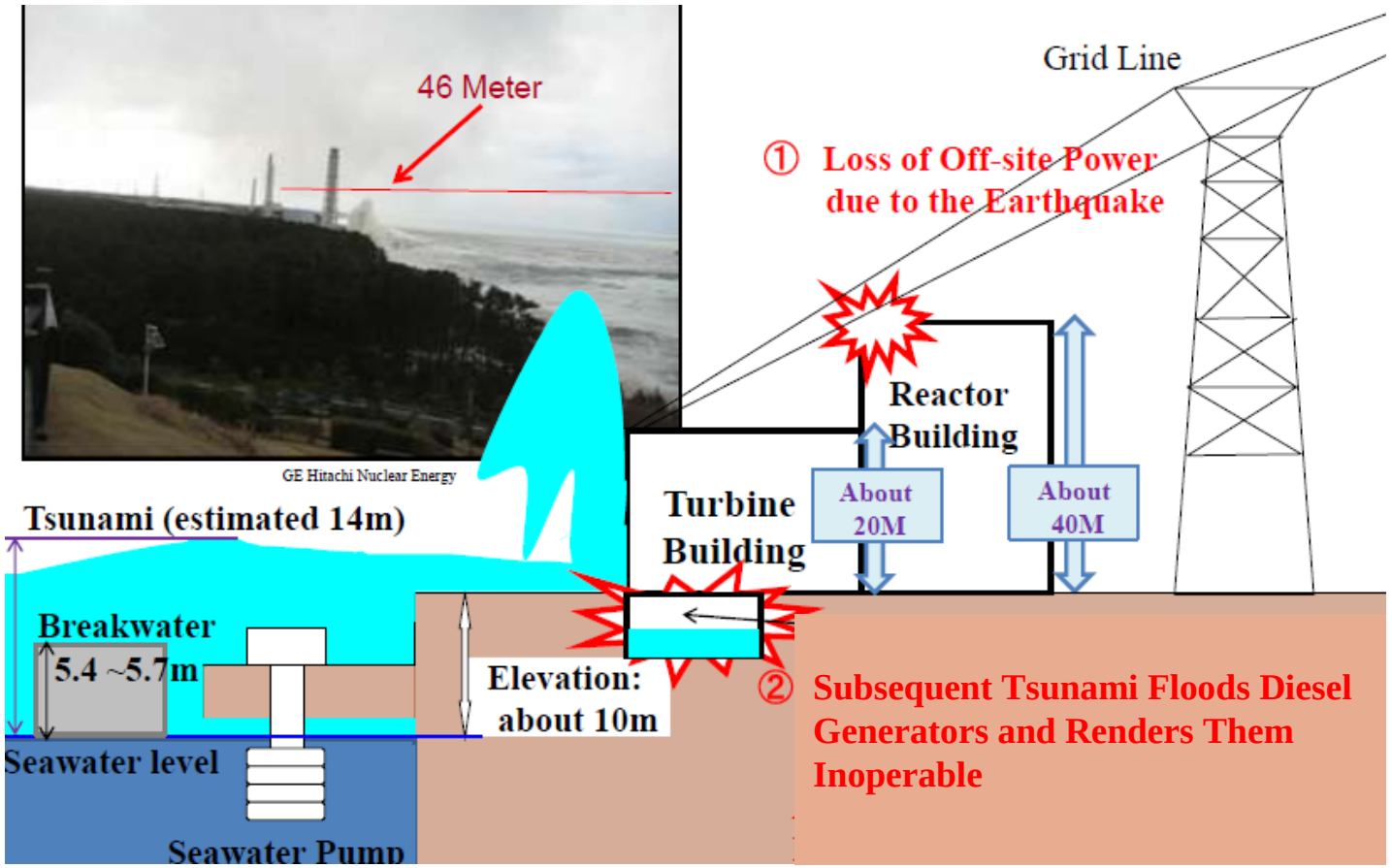






Root Cause of Damage

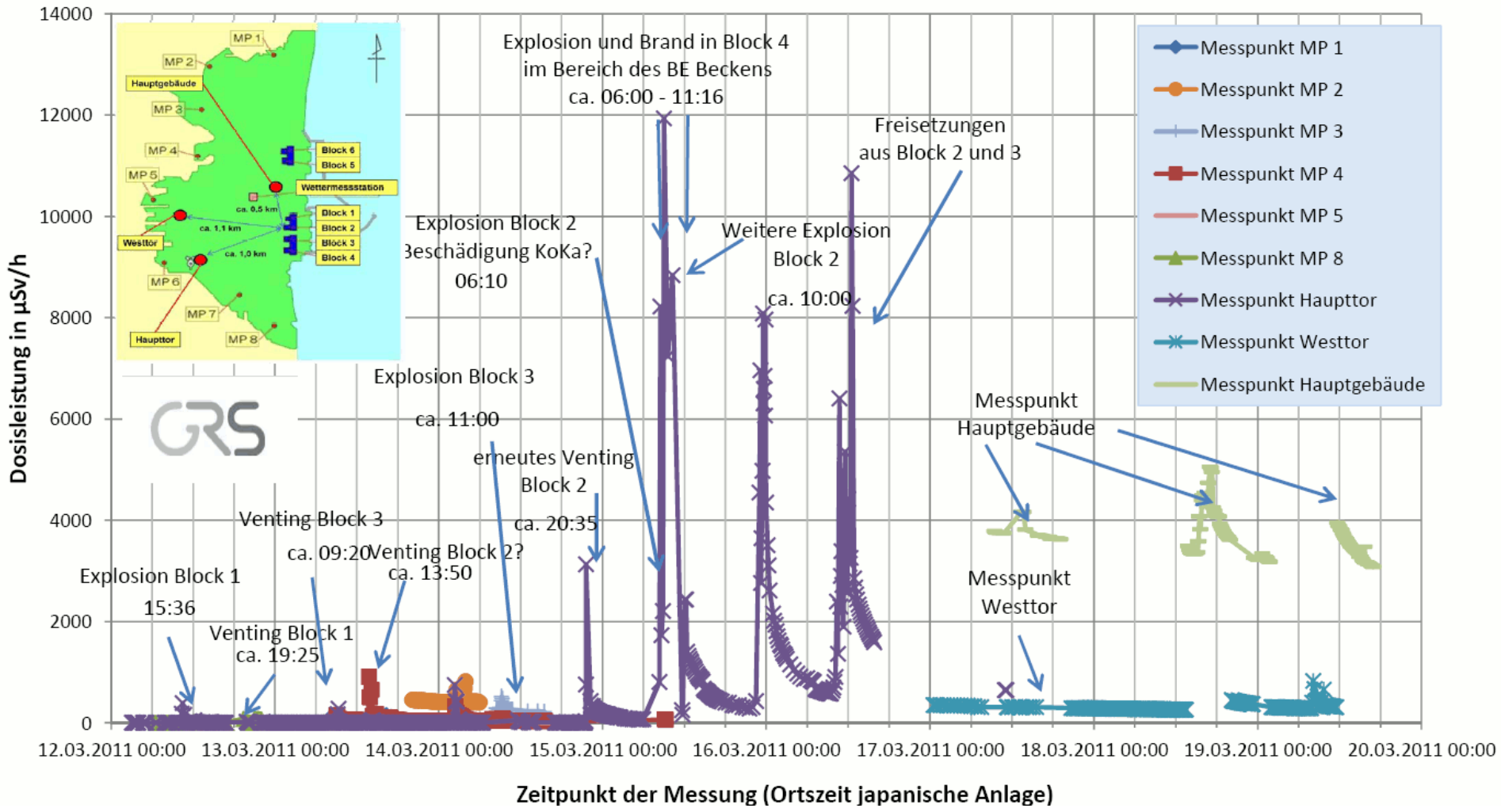
- The ~14 m Tsunami was ~ 9 m greater than the site design basis height of 5.4 m.
- The water completely inundated Units 1-4 knocking out diesel generators, leading to a 'station blackout sequence.'




重油タンク

Release Scenarios

- After batteries ran dry, loss of core cooling led to coolant boil-down, uncovered fuel, decay heat buildup and fuel-rod degradation. Due to the lack of heat sink, the containments pressurized and **venting commenced**
- Zr cladding oxidation from exposed fuel lead to H_2 release that apparently found its way into the reactor buildings
- **Explosions (most likely H_2 detonations) in Units 1 and 3** occurred on 3/12 and 3/14, damaging the reactor building upper structure (not containment boundary).
- During these events, site personnel also struggled to keep the spent fuel pool ponds covered with water, particularly for Unit 4 that contained a full core off-load
  - **Explosion at unit 4 on 3/14, presumably H_2 detonation**
- Contaminated water leaks and deliberate water releases to ocean mid- to late March
- Multiple release scenarios and pathways to the environment


Dosisleistung in µSv/h
14000
12000
10000
8000
6000
4000
2000
0
12.03.2011 00:00
13.03.2011 00:00
14.03.2011 00:00
15.03.2011 00:00
16.03.2011 00:00
17.03.2011 00:00
18.03.2011 00:00
19.03.2011 00:00
20.03.2011 00:00
Zeitpunkt der Messung (Ortszeit japanische Anlage)
Explosion und Brand in Block 4
im Bereich des BE Beckens
ca. 06:00 - 11:16
Freisetzungen
aus Block 2 und 3
Explosion Block 2
Beschädigung KoKa?
06:10
Weitere Explosion
Block 2
ca. 10:00
Explosion Block 3
ca. 11:00
erneutes Venting
Block 2
ca. 20:35
Venting Block 3
ca. 09:20
Venting Block 2?
ca. 13:50
Explosion Block 1
15:36
Venting Block 1
ca. 19:25
Messpunkt
Hauptgebäude
Messpunkt
Westtor
Messpunkt MP 1
Messpunkt MP 2
Messpunkt MP 3
Messpunkt MP 4
Messpunkt MP 5
Messpunkt MP 8
Messpunkt Haupttor
Messpunkt Westtor
Messpunkt Hauptgebäude
MP 1
MP 2
Hauptgebäude
MP 3
MP 4
MP 5
Block 6
Block 5
Wettermessstation
ca. 0,5 km
ca. 1,1 km
Westtor
ca. 1,0 km
Block 1
Block 2
Block 3
Block 4
MP 6
MP 7
Haupttor
MP 8
GRS

Radionuclides of Primary Concern

Revised April 2003 — Nuclear Power Plant Accident

Plume Phase

^{88}Kr, ^{133}Xe, ^{135}Xe
^{131}I, ^{132}I, ^{133}I, ^{135}I
^{131m}Te, ^{132}Te, ^{129}Sb

First Year

^{131}I, ^{132}Te
^{134}Cs, ^{136}Cs, ^{137}Cs
^{103}Ru, ^{106}Ru
^{140}Ba, ^{140}La
^{95}Nb, ^{95}Zr
^{141}Ce, ^{144}Ce
^{238}Pu, ^{241}Pu

Radionuclides Observed

I-131	8.02 days	Cs-134	2.07 years
I-132	2.3 hours	Cs-136	13.04 days
Te-132	3.2 days	Cs-137	30.03 years
I-133	20.8 hours	La-140	1.7 days
Te-129m	33.6 days		

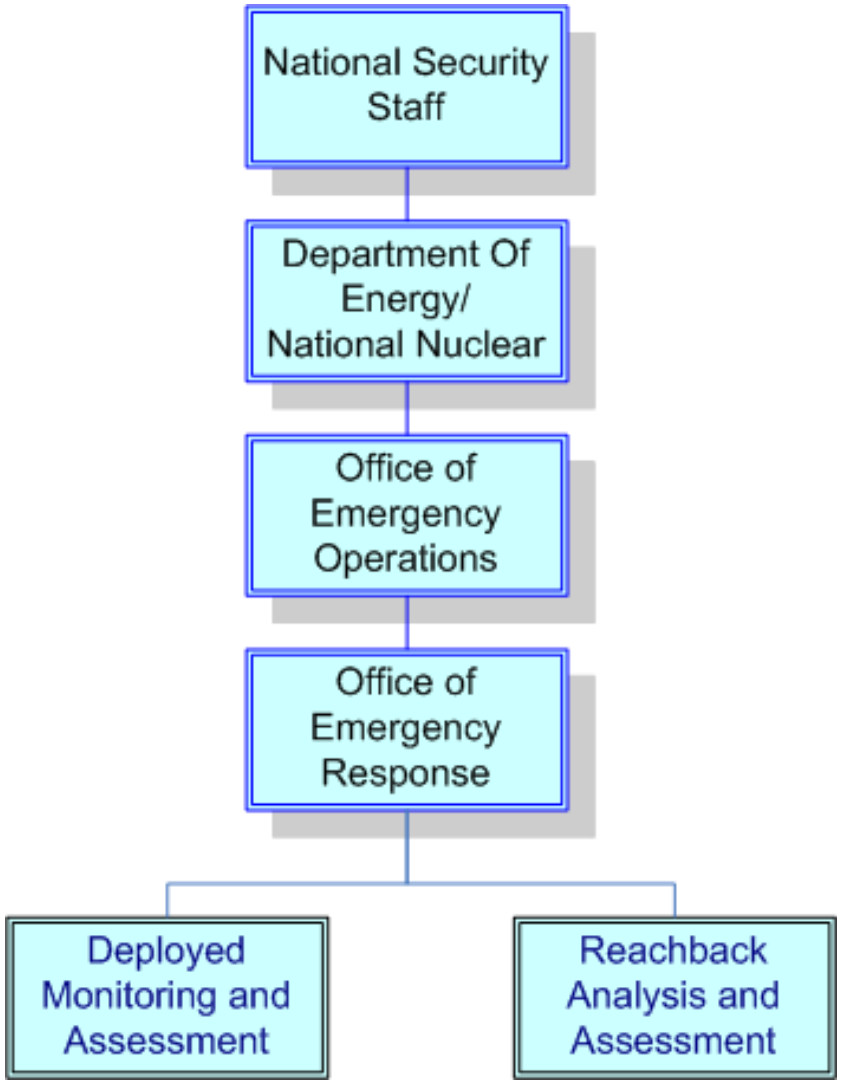
Public Protection Measures

- March 12: Government of Japan established mandatory evacuation zone for people living within a 20 km radius of the Fukushima Daiichi NPP and recommended shelter-in-place for people living within 20-30 km
- March 13: US Embassy issued an advisory restricting travel US citizens within 80 km of the Fukushima NPP
- March 16: US Embassy and US Forces Japan (USFJ) authorized voluntary departure for dependents

DOE Support to Operation Tomodachi

Mission:

Assess the consequences of releases from the Fukushima Dai-ichi Nuclear Power Plant (FDNPP)



Initial DOE Deployment

- March 14, 2011
  - At White House direction, DOE deployed a tailored CMRT and AMS capability via military airlift (C-17) to Yokota Air Base

DOE Timeline (cont'd)

- March 16
  - CM Assets arrive at Yokota AB and fly first AMS test flight
- March 17
  - First aerial measurement activities over plant conducted; first field monitoring mission completed
- March 22
  - Initial data published on DOE website

Argonne Deployments

- Frank Moore and Steve Bettenhausen deployed April 5th thru April 29th
- Dave Chamberlain deployed April 19th thru May 6th
- Ray Klann deployed May 4th thru May 16th

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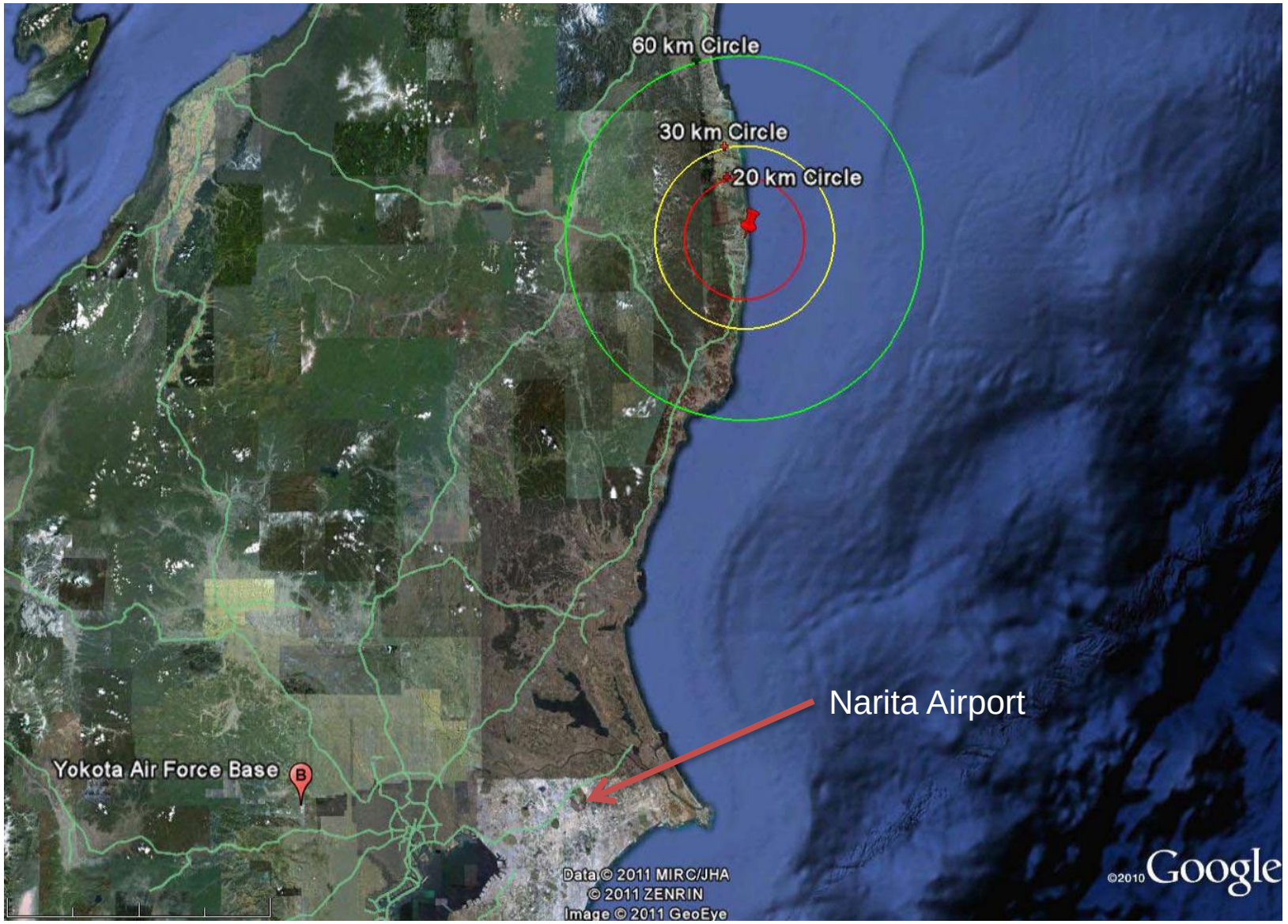
Yokota AFB – 145 miles to Reactors



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Yokota Air Base

Hangar 1503: DOE's home at Yokota AB

Tent in background is AFRAT's lab

Field Team

Composition

- Small field footprint with large capability
- 33 personnel to Yokota AB
  - 12 scientists of many disciplines (nuclear, GIS, environmental, 5 PhDs, 2 CHPs)
  - Technicians with a diverse skill set
- 1 DOE HQ liaison to US embassy, Tokyo

AERIAL MEASURING SYSTEM ACTIVITIES

Aerial Monitoring

What was done

- Fixed wing and helicopter
- Up to 3 aircraft per day
- Surveys over US bases
- Joint DOE & GOJ survey

Why it was done

- Map ground deposition out to 80 km from FDNPP
- Support evacuation, relocation, agricultural decisions

AMS on USAF Aircraft

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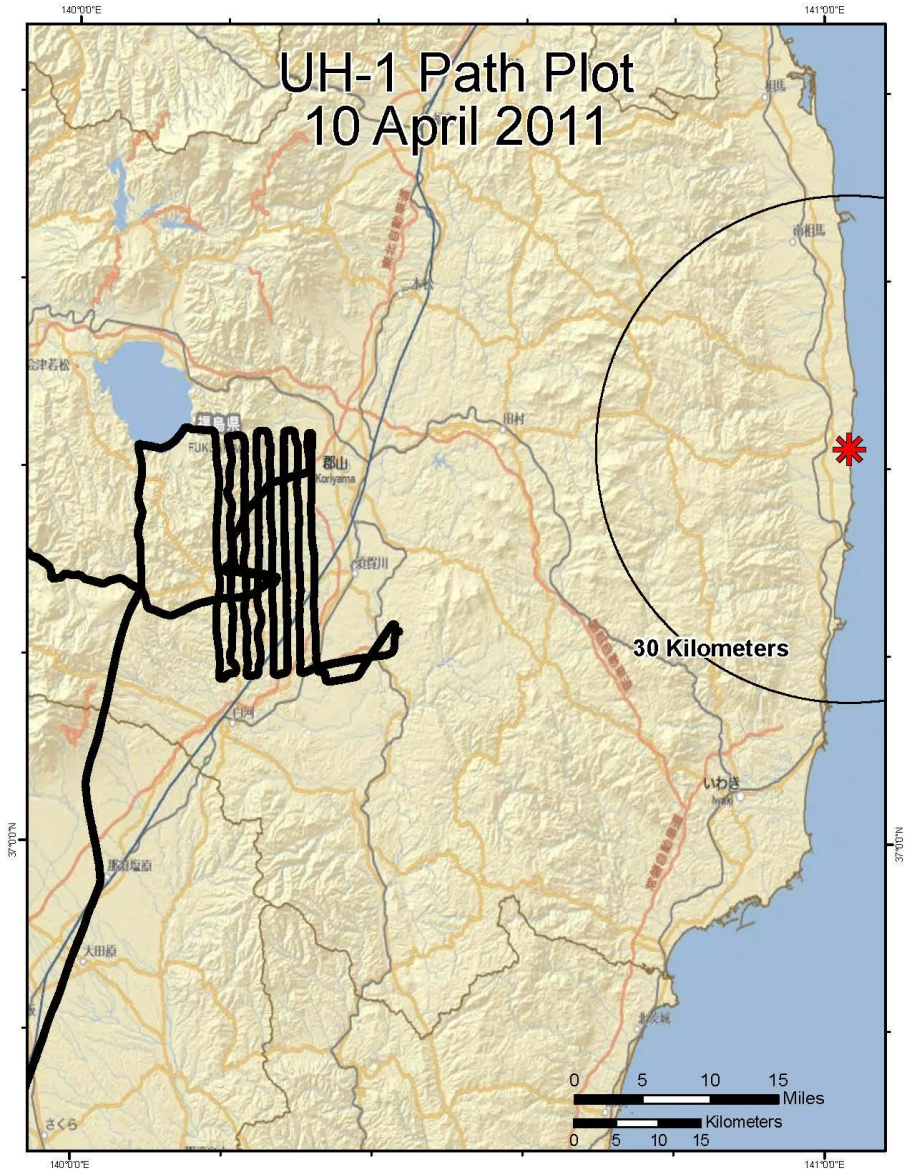
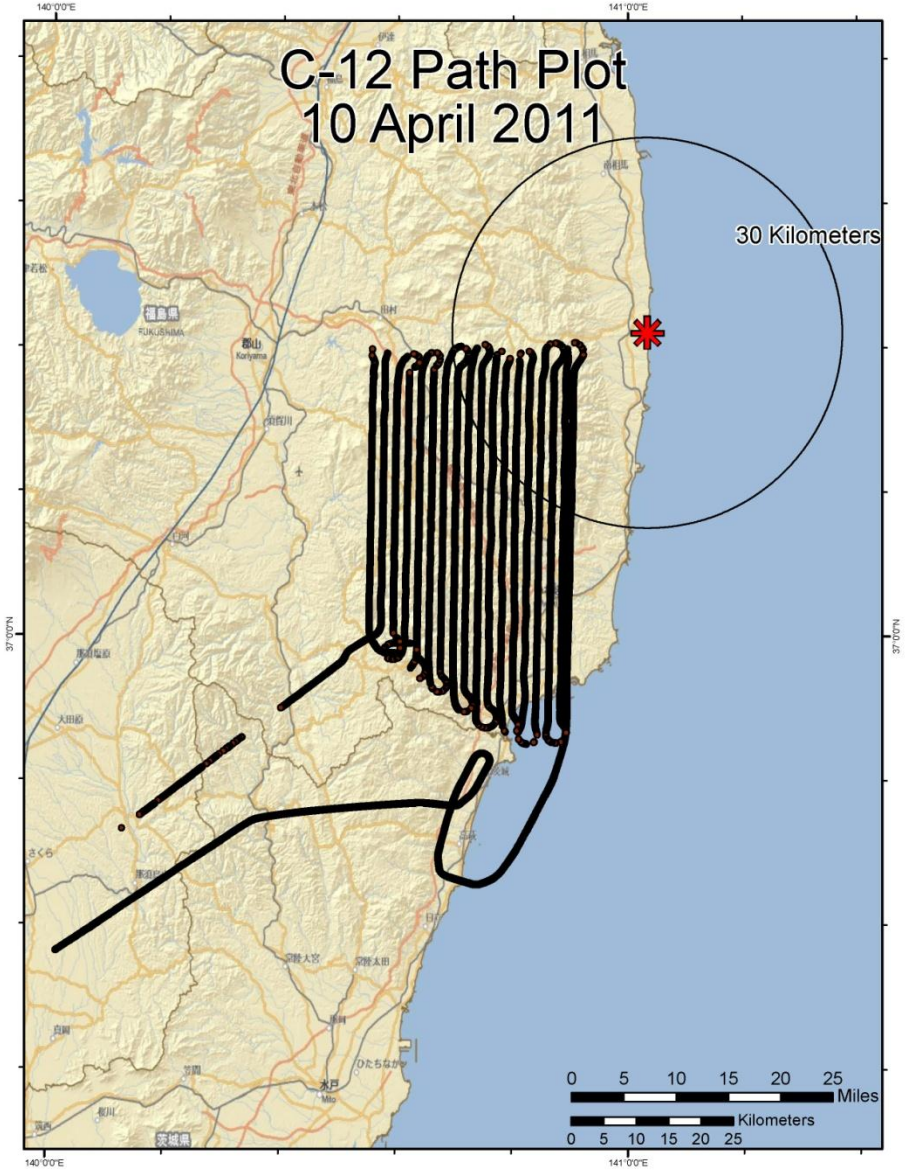
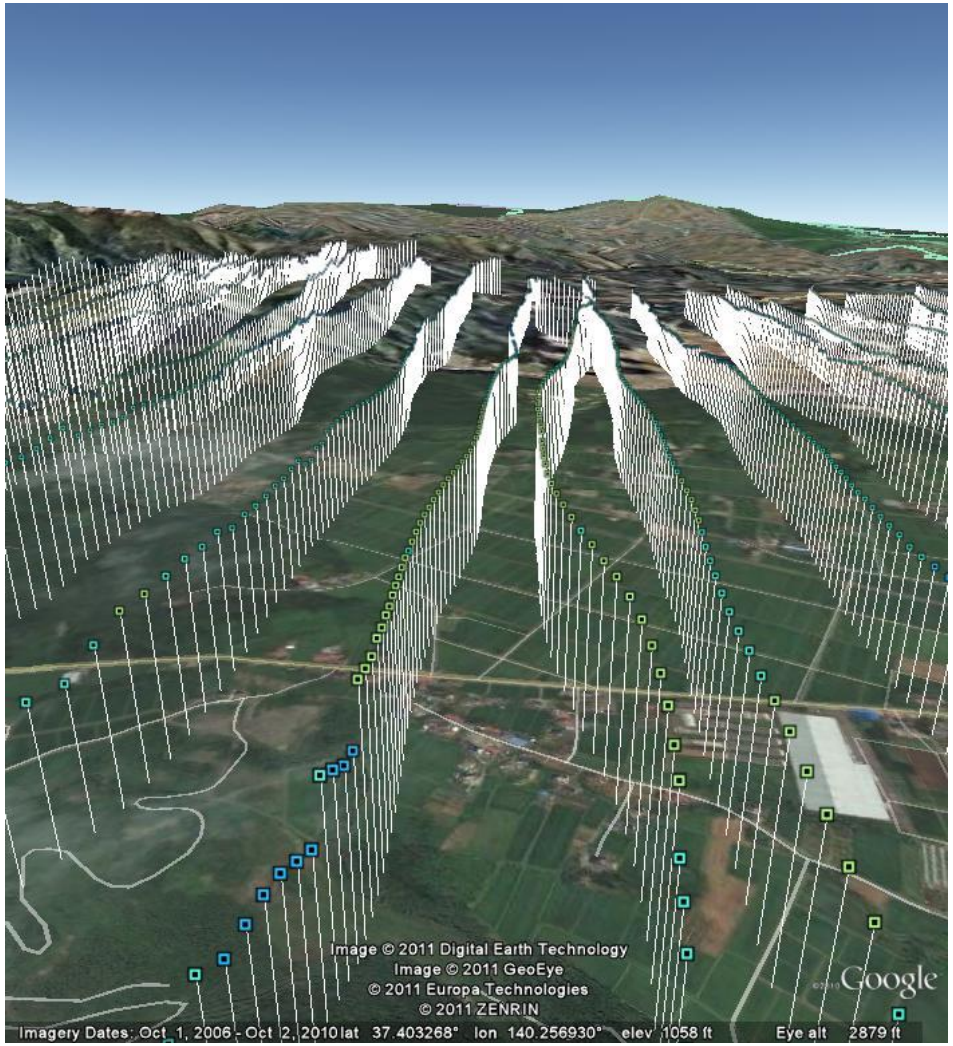
Typical flight path





AMS Altitude Correction



- Nominal flying altitude (H_{AGL}) of 500ft (UH-1) or 1000ft (C-12)
- Line spacing 2x H_{AGL}
- Actual height above ground level (AGL) derived from GPS altitude and Japan Digital Elevation Model (DEM)
  - $H_{AGL} = H_{GPS} - H_{DEM}$
- Measured gamma exposure-rate readings corrected to 1 meter above the ground using H_{AGL}
  - $R_{1m} = R_{H_{AGL}}\ e^{\mathbf{u}H_{AGL}}$
- Average exposure-rate attenuation coefficient **u** determined empirically from calibrated flight line in the US
- Corrected exposure rate “calibrated” by ground-level measurements by field monitoring teams

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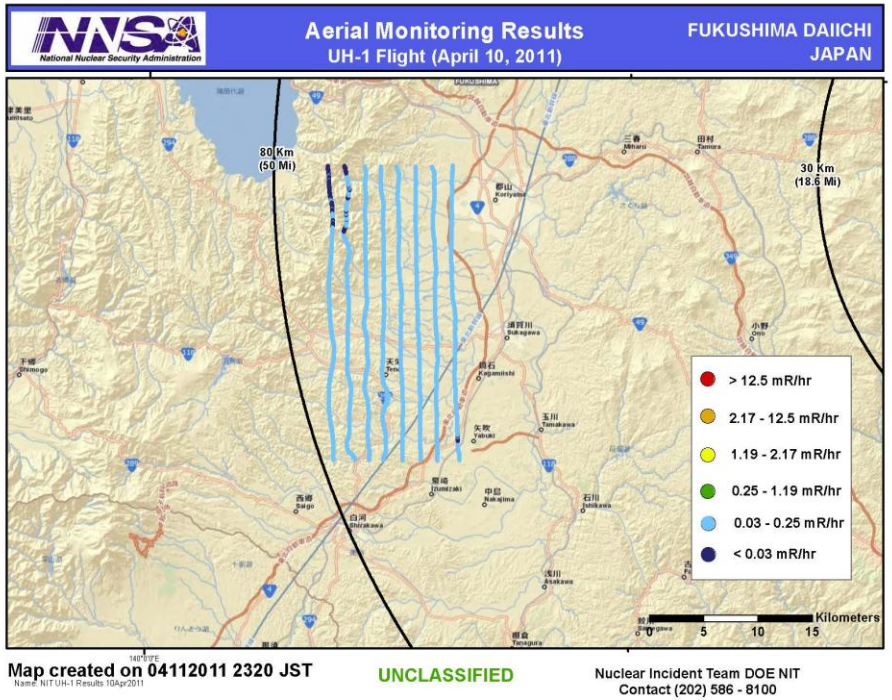
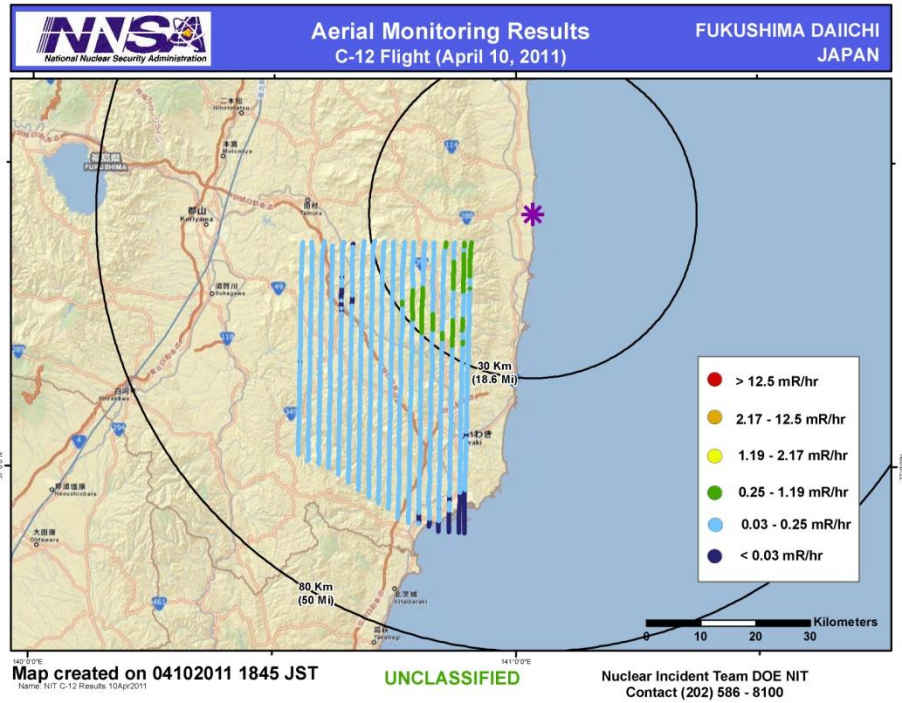
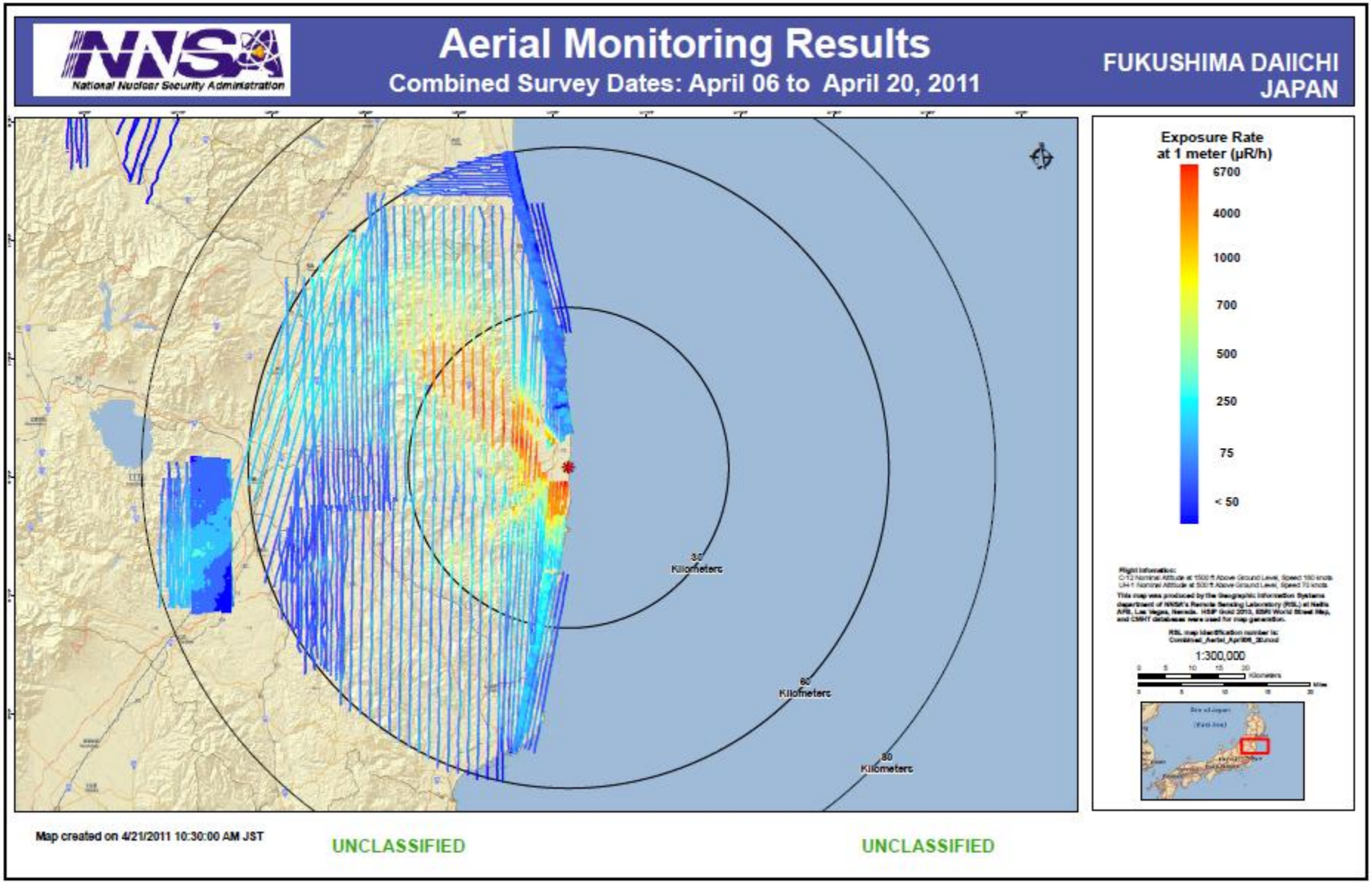
Typical Results





Composite Results



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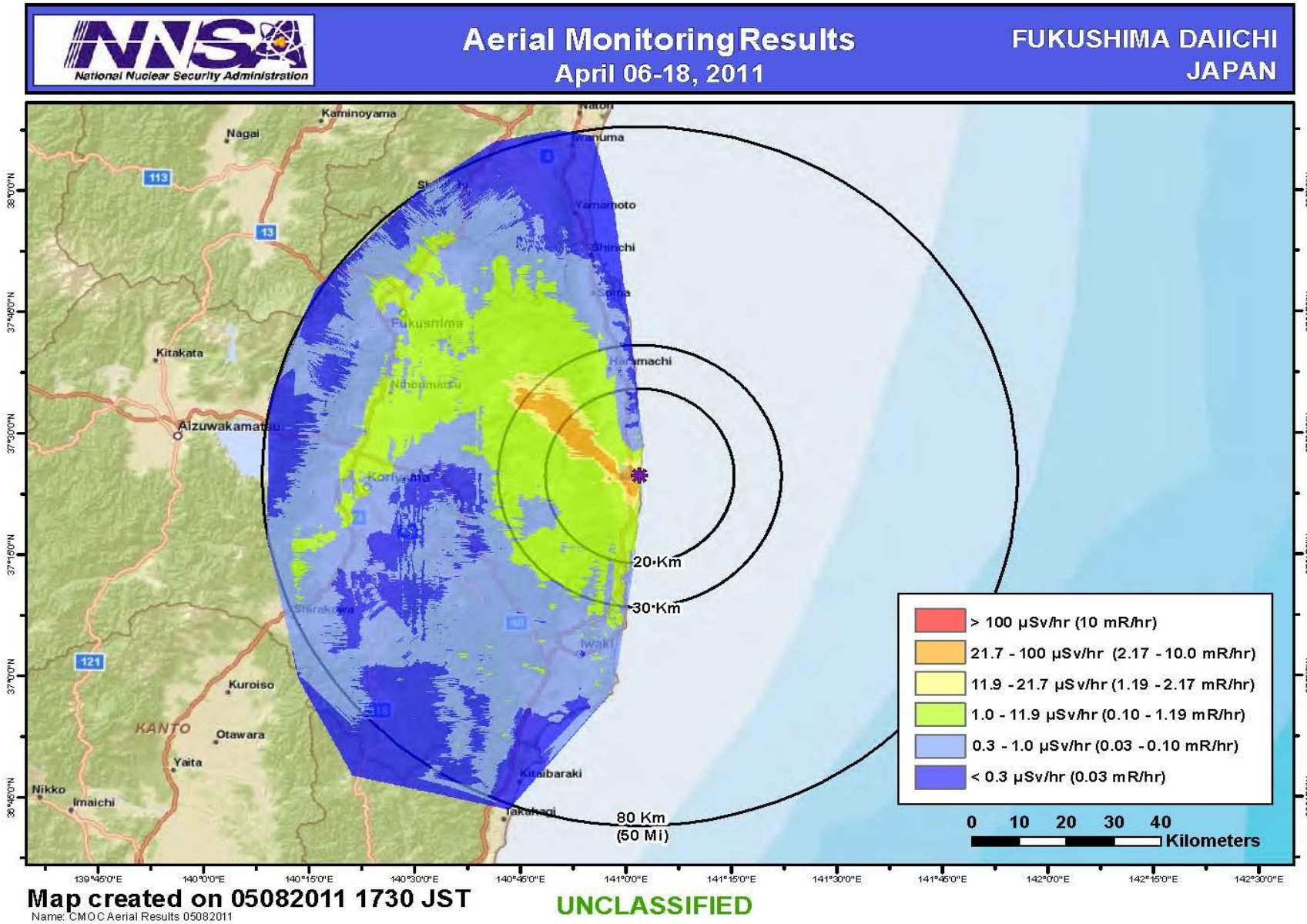
Interpolated Exposure Rate Map



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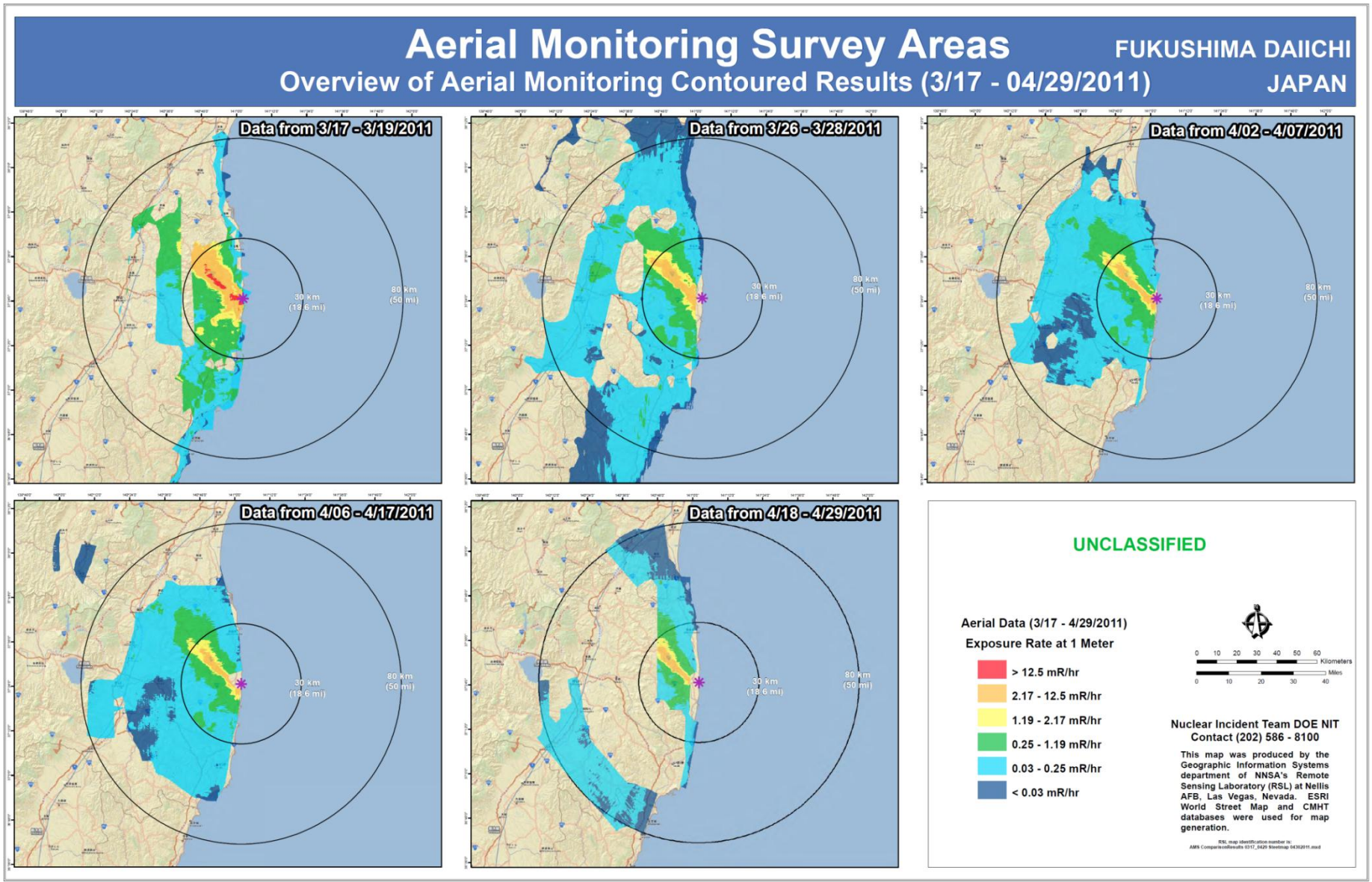
Time-Sequenced Exposure Rate



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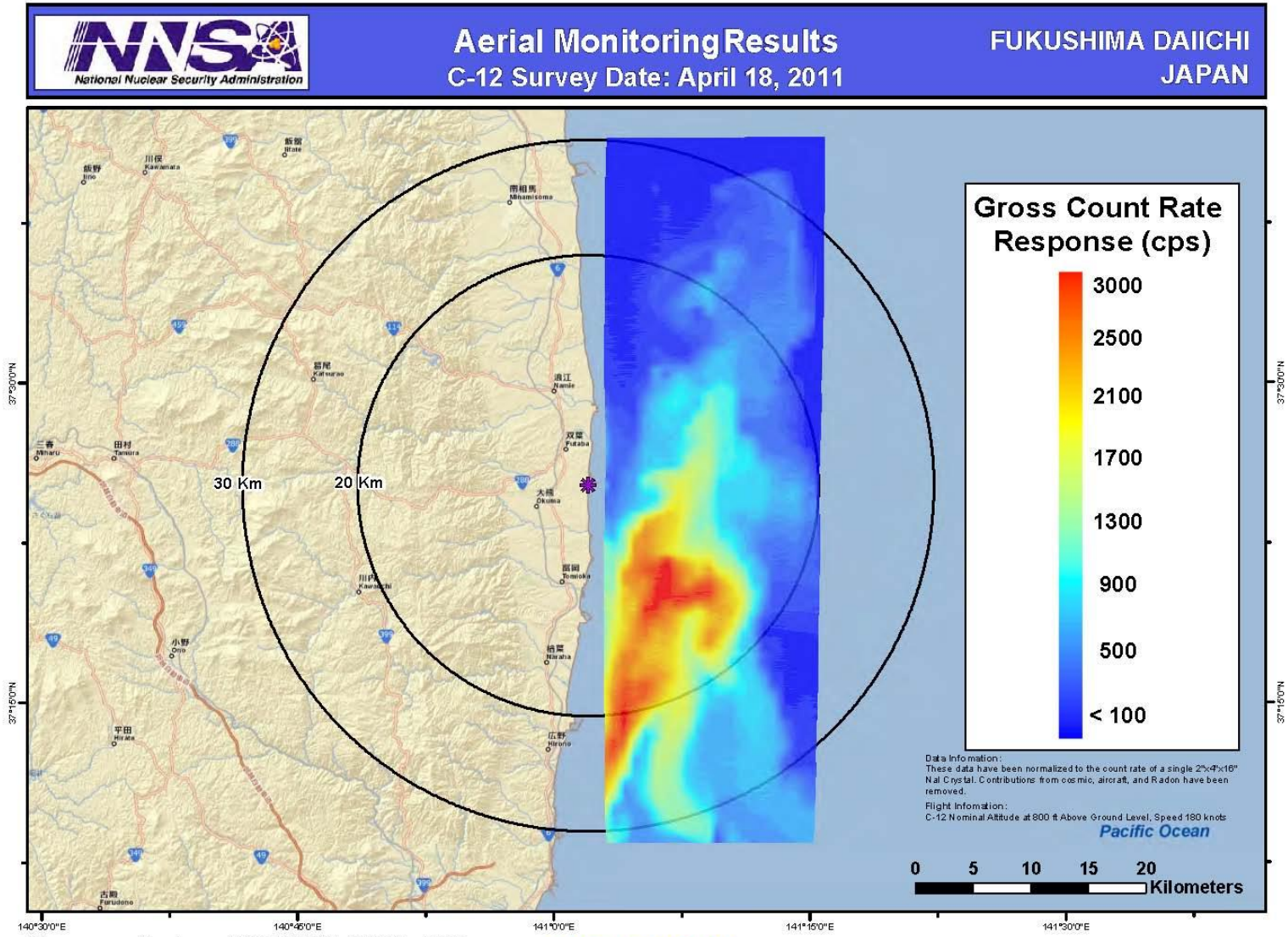
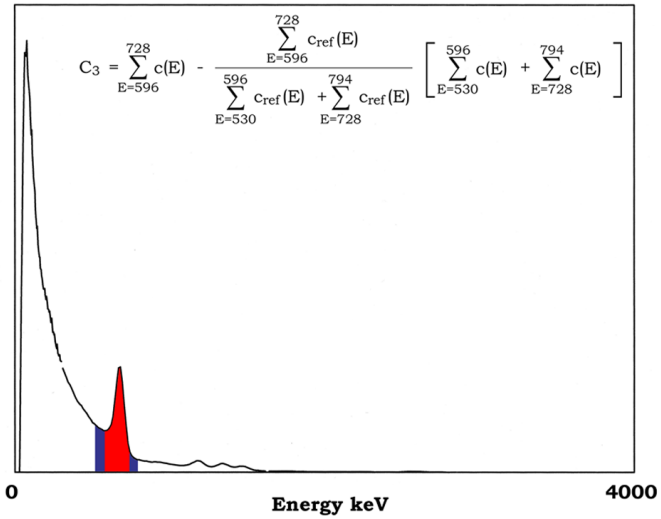
Sea Water Release

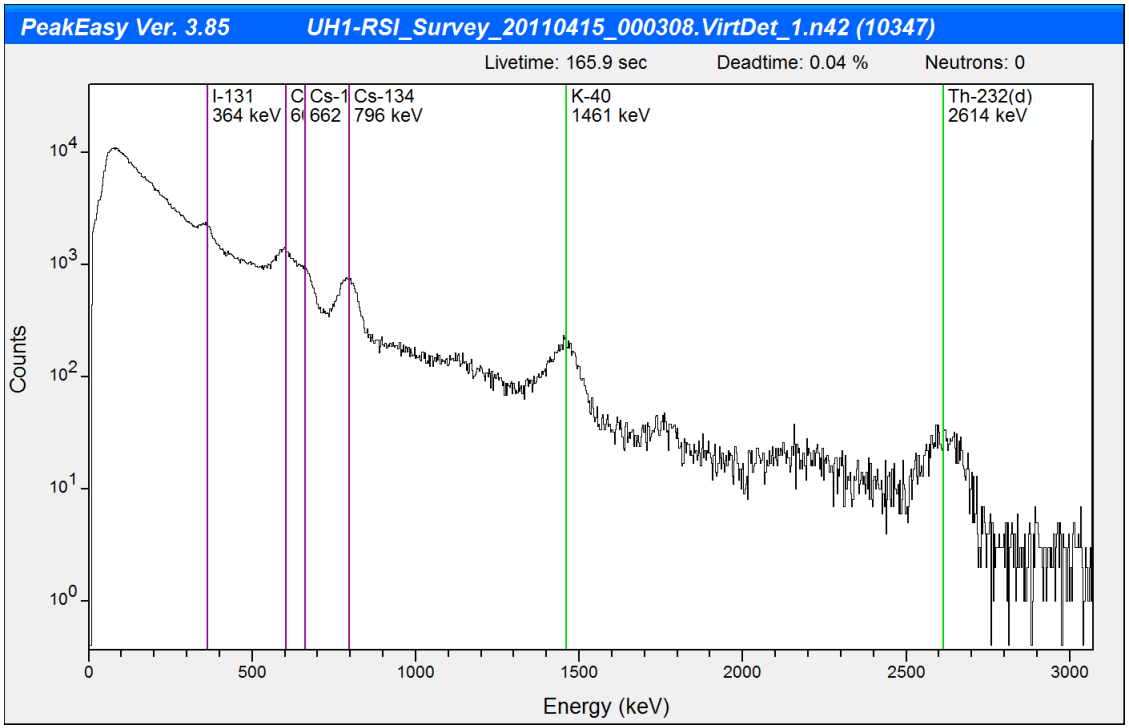


Gamma-Spec Isotopic Extraction



$$Cs-137(3win) = \sum_{E=596}^{728} S(E) - k * \left[\sum_{E=530}^{596} S(E) + \sum_{E=728}^{794} S(E) \right]$$

$$k = \sum_{E=596}^{728} S_{ref}(E) / \left[\sum_{E=530}^{596} S_{ref}(E) + \sum_{E=728}^{794} S_{ref}(E) \right]$$



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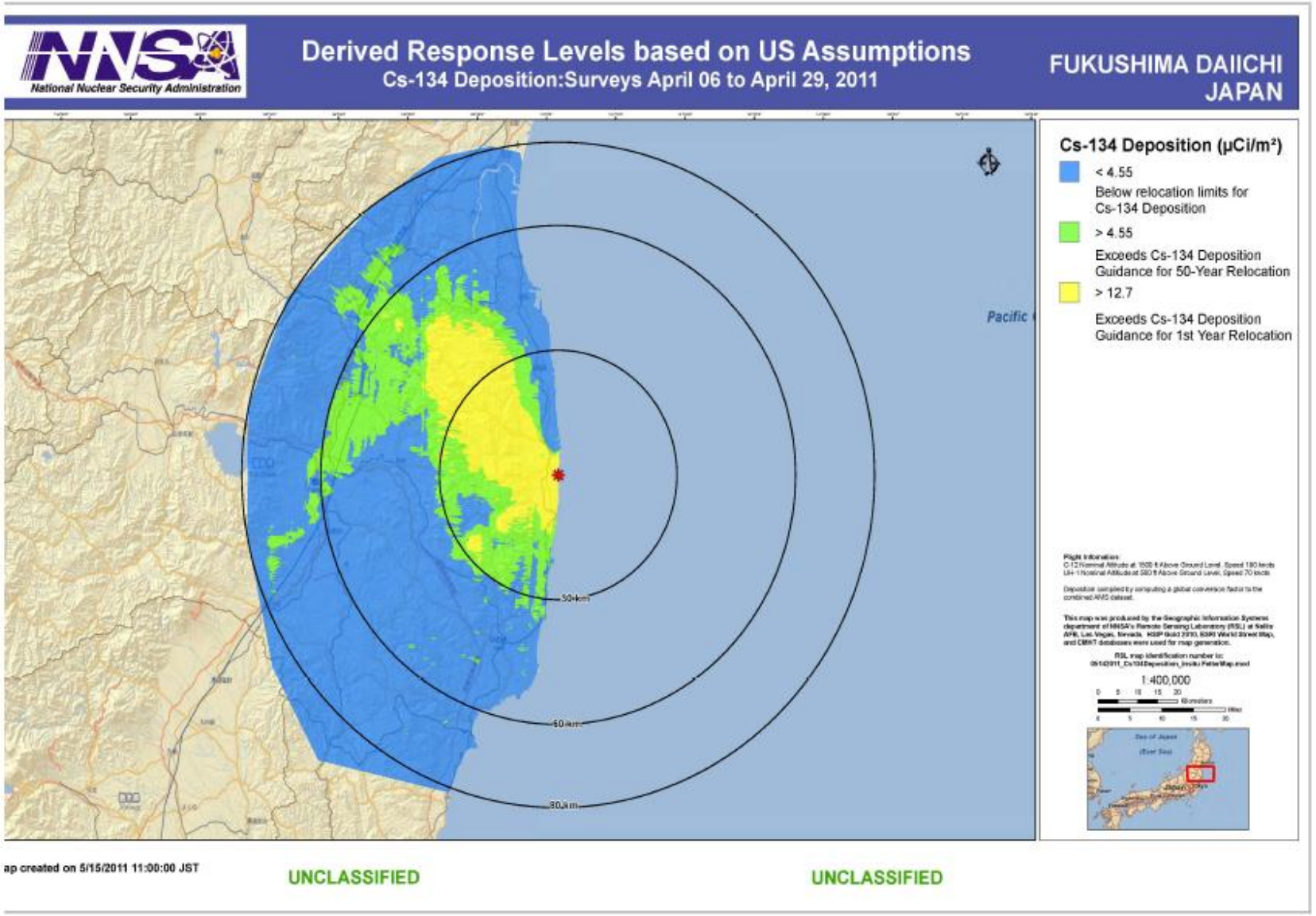
Gamma-Spec Isotopic Extraction



Uncertainties for AMS Measurements

- Altitude and atmospheric pressure corrections
- Attenuation through aircraft skin
- Radon and cosmic-ray contributions
- Short-scale spatial variations in activity distribution (hotspots)
- Positional
  - GPS
  - Velocity along flight direction
- Detector response
- Ground-based corrections

Ground monitoring

What was done

- Mobile monitoring
- In-situ measurements
- Exposure rate measurements
- Air sampling
- Soil samples/core samples
- Swipes

Why it was done

- Calibrate aerial measurements
- Define Isotopic mix
- Characterize the inhalation component of integrated dose
- Assess vertical and horizontal migration of deposited material

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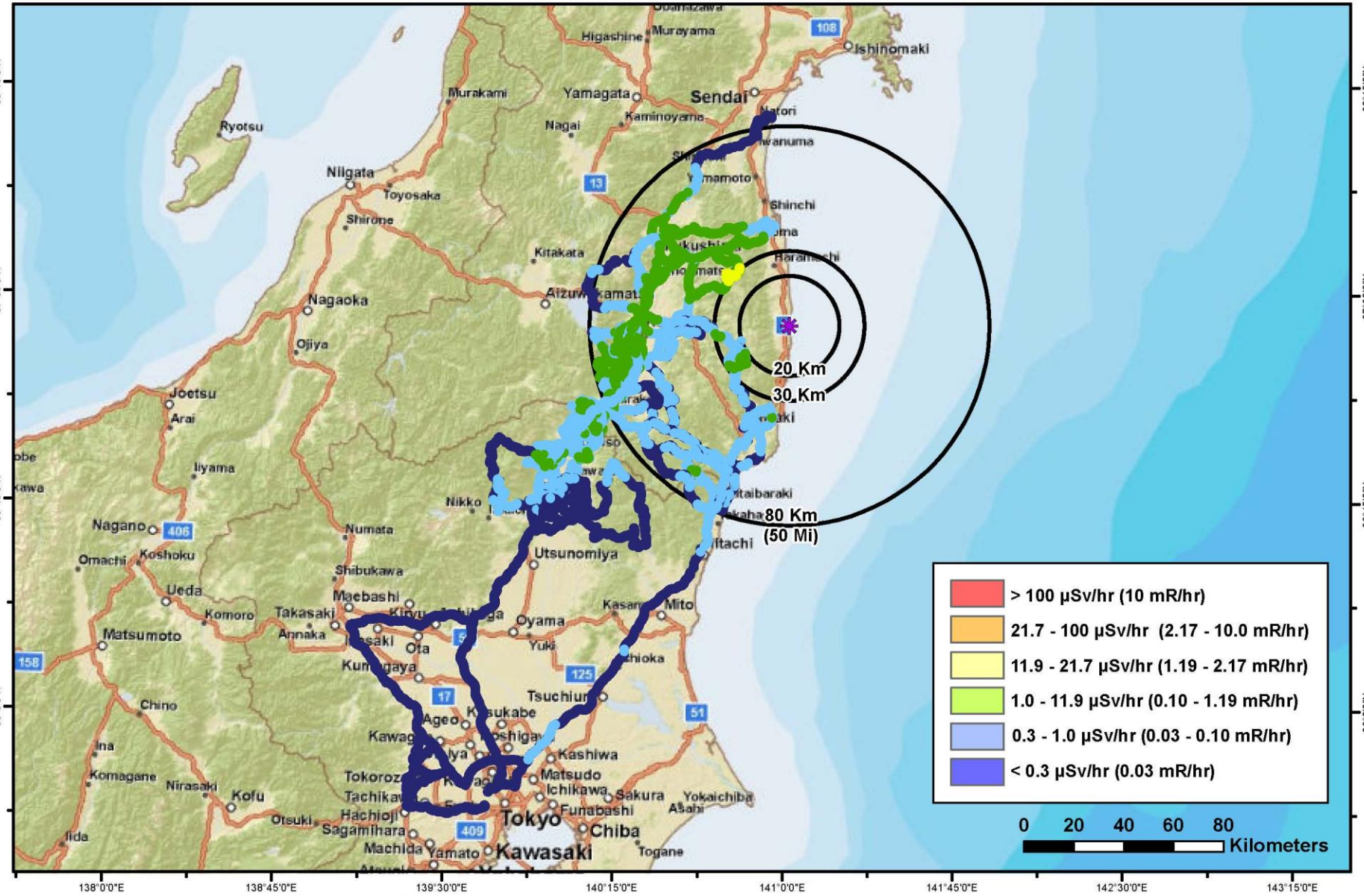
Mobile monitoring

National Nuclear Security Administration

Mobile Monitoring Results

April 10 - May 05, 2011

FUKUSHIMA DAIICHI JAPAN



Map created on 05082011 1730 JST

Name: CMOC Mobilel Results 05082011

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Mobile Monitoring Results

Tohoku Expressway Survey

National Nuclear Security Administration

FUKUSHIMA DAIICHI
JAPAN

Map created on 4/25/2011 6:30:00 PM JST

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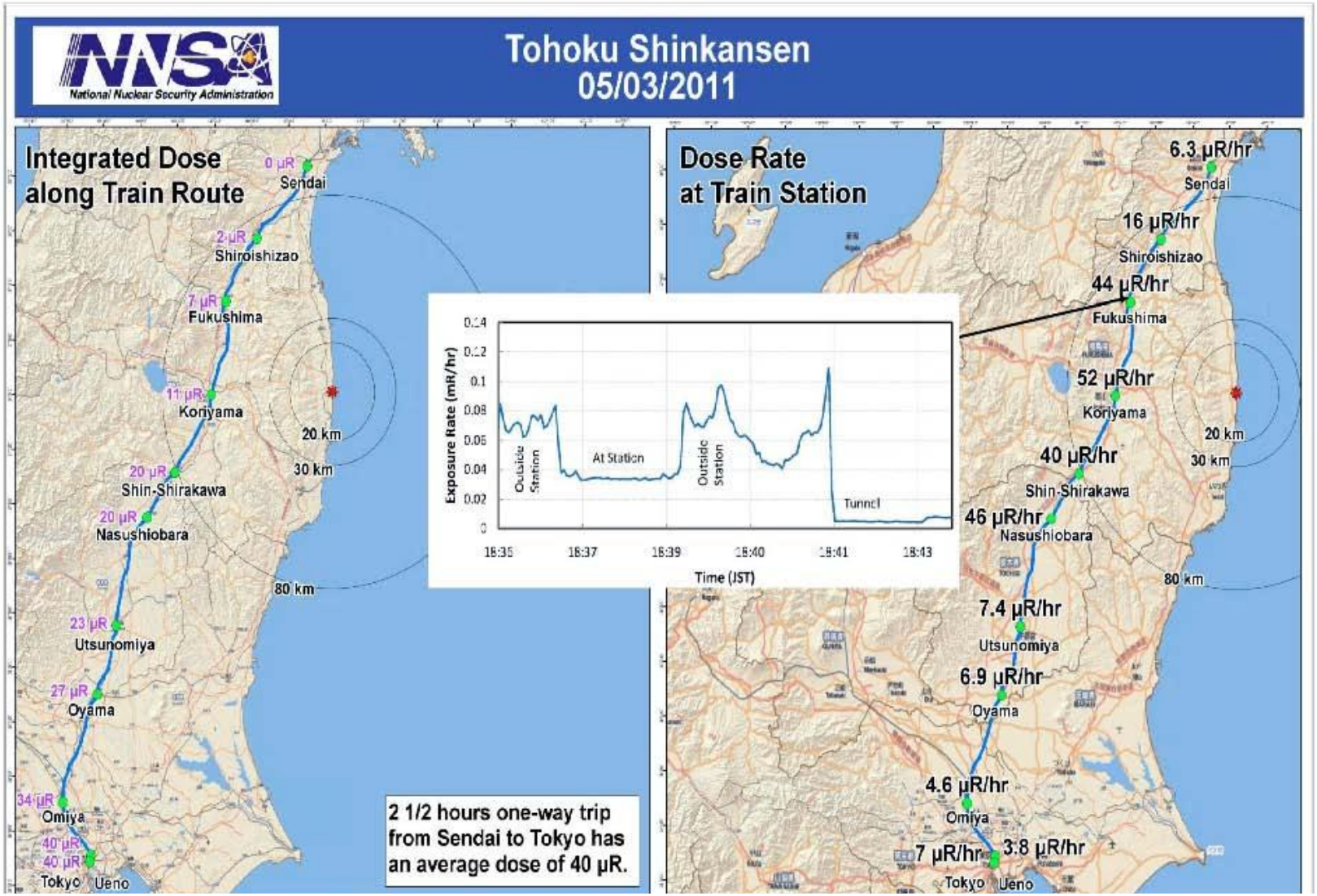
Monitoring Results: Sendai to Tokyo



Note: 1 milliRem (mRem) = 10 microSieverts;
1 milliRem (mRem) = 1000 microrem

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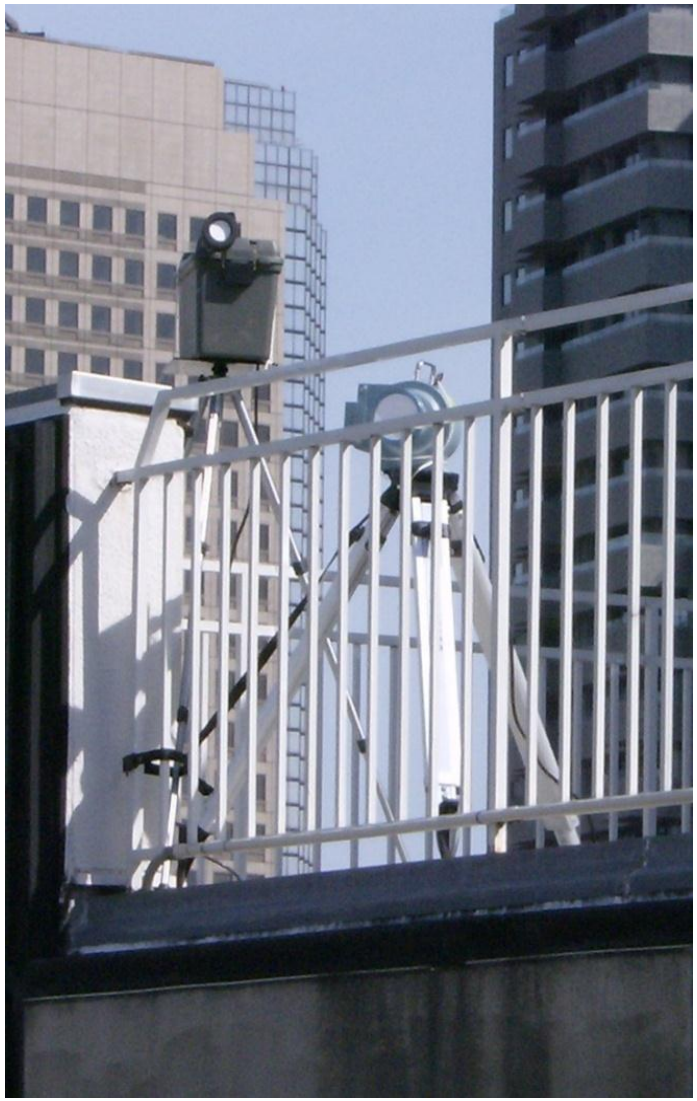
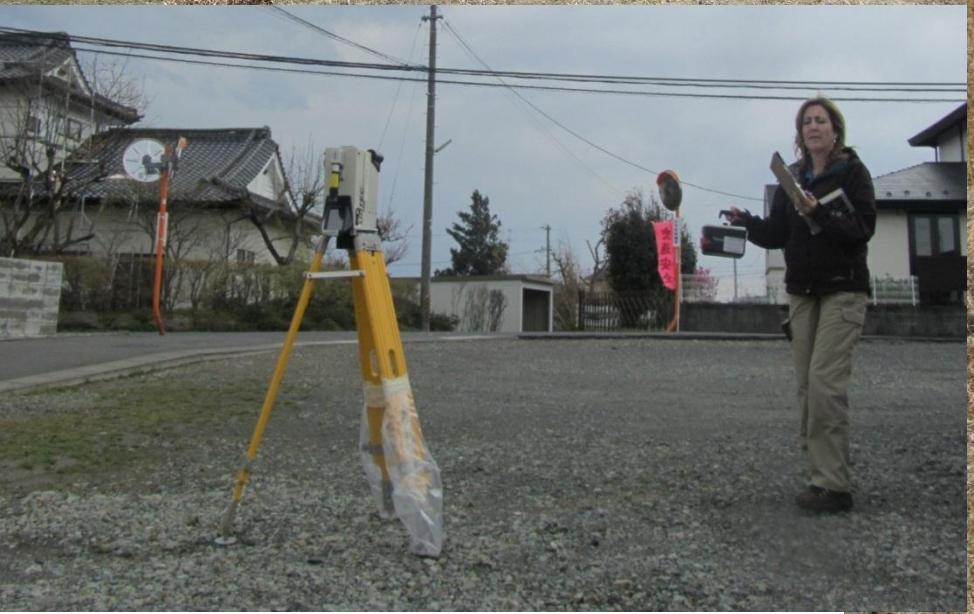
Exposure rate measurements

Air sampling

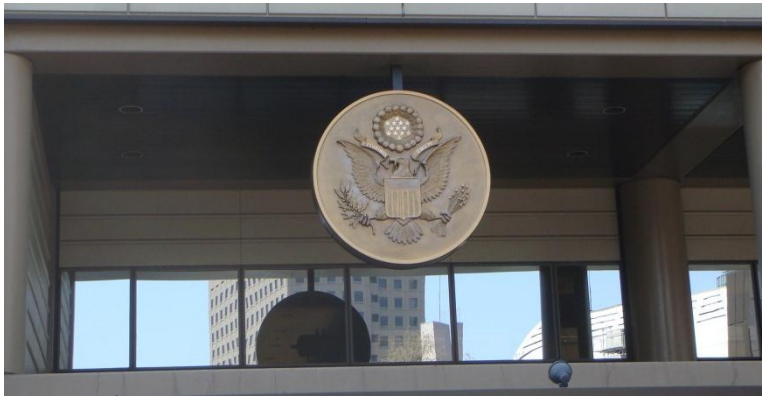


U.S. DEPARTMENT OF ENERGY *In Situ* HPGe Measurements

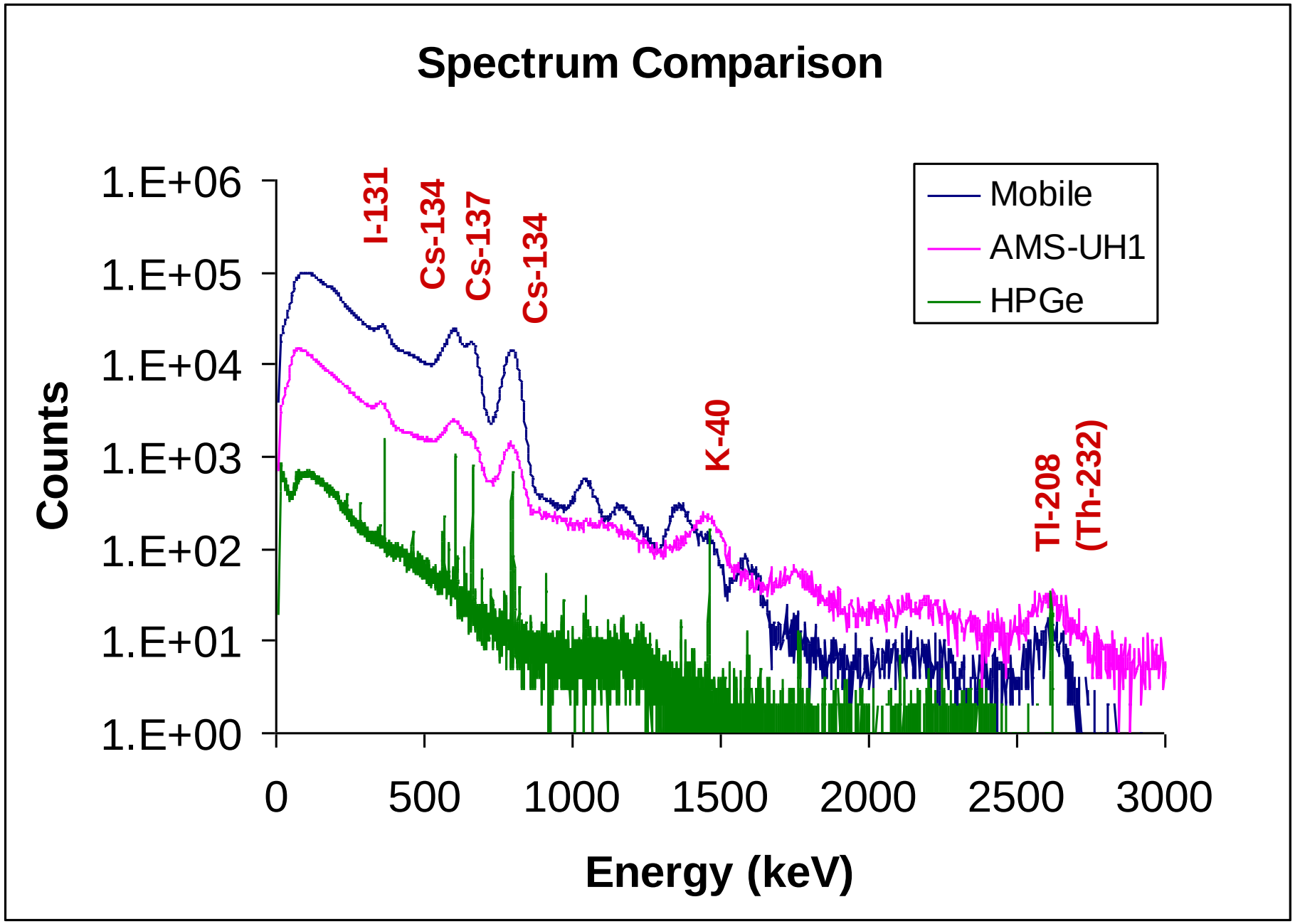


- Mechanically cooled HPGe
- 15% Relative Efficiency p-type
- 1 meter above surface

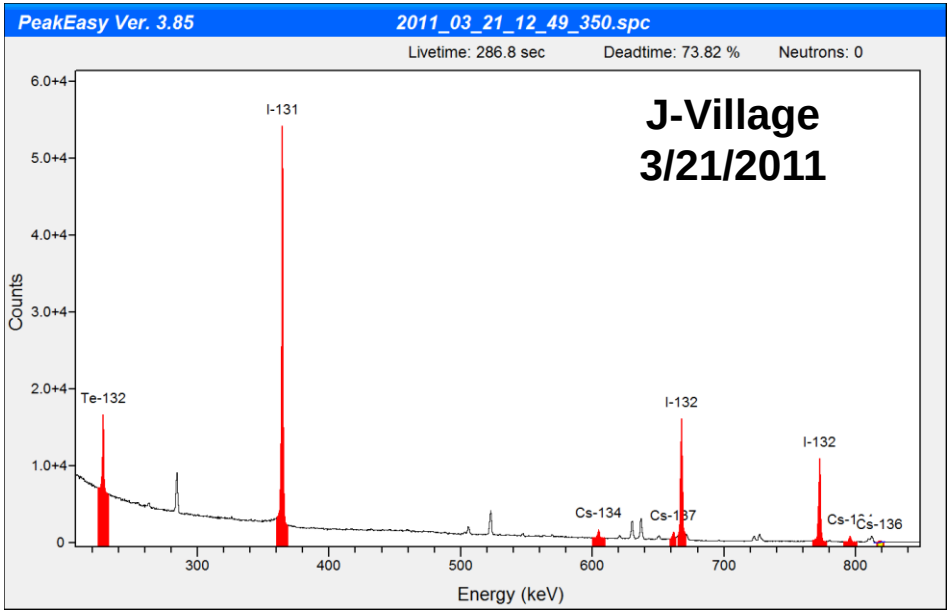
U.S. Embassy Tokyo

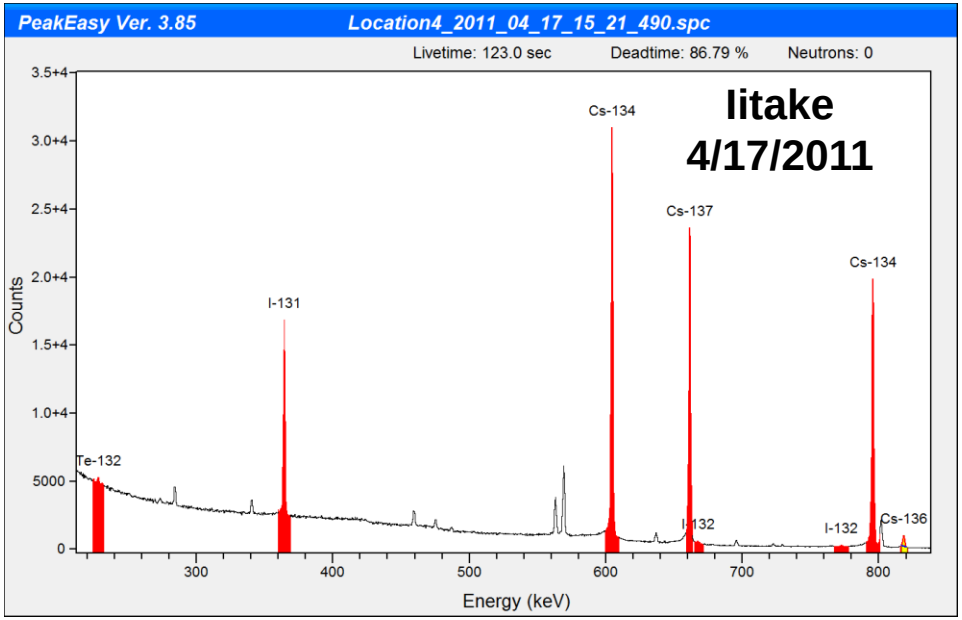


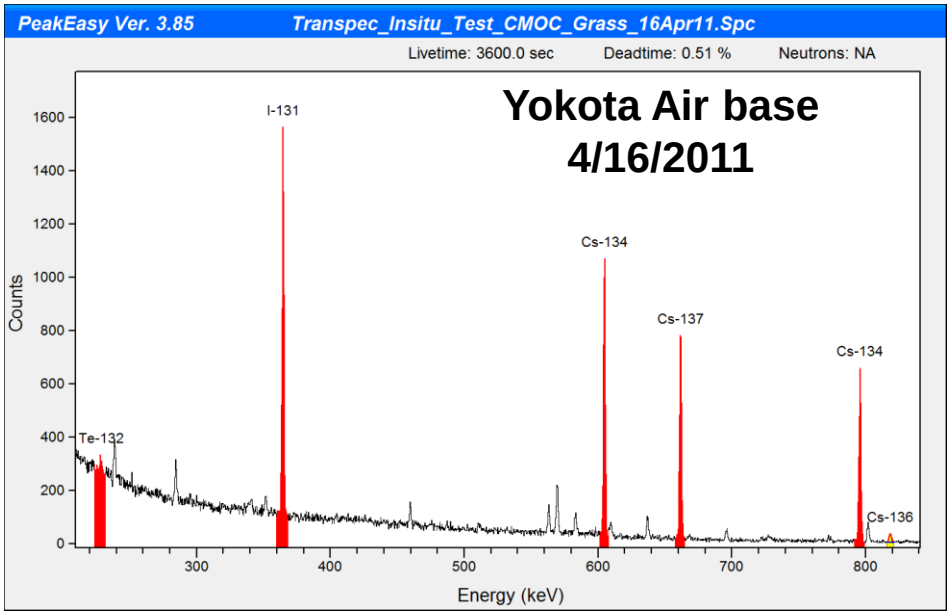
- 3 Days prior to Sec. Clinton visit
- Concern for Embassy Personnel

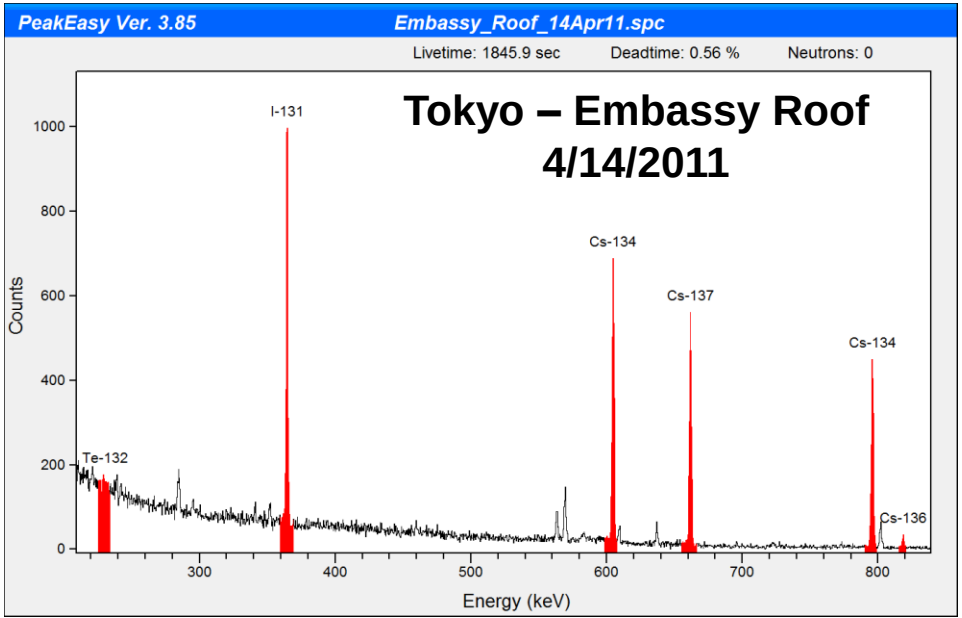

Spectrum Comparison
Counts
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0
500
1000
1500
2000
2500
3000
Energy (keV)
I-131
Cs-134
Cs-137
Cs-134
K-40
Tl-208
(Th-232)
Mobile
AMS-UH1
HPGe

In Situ Spectra





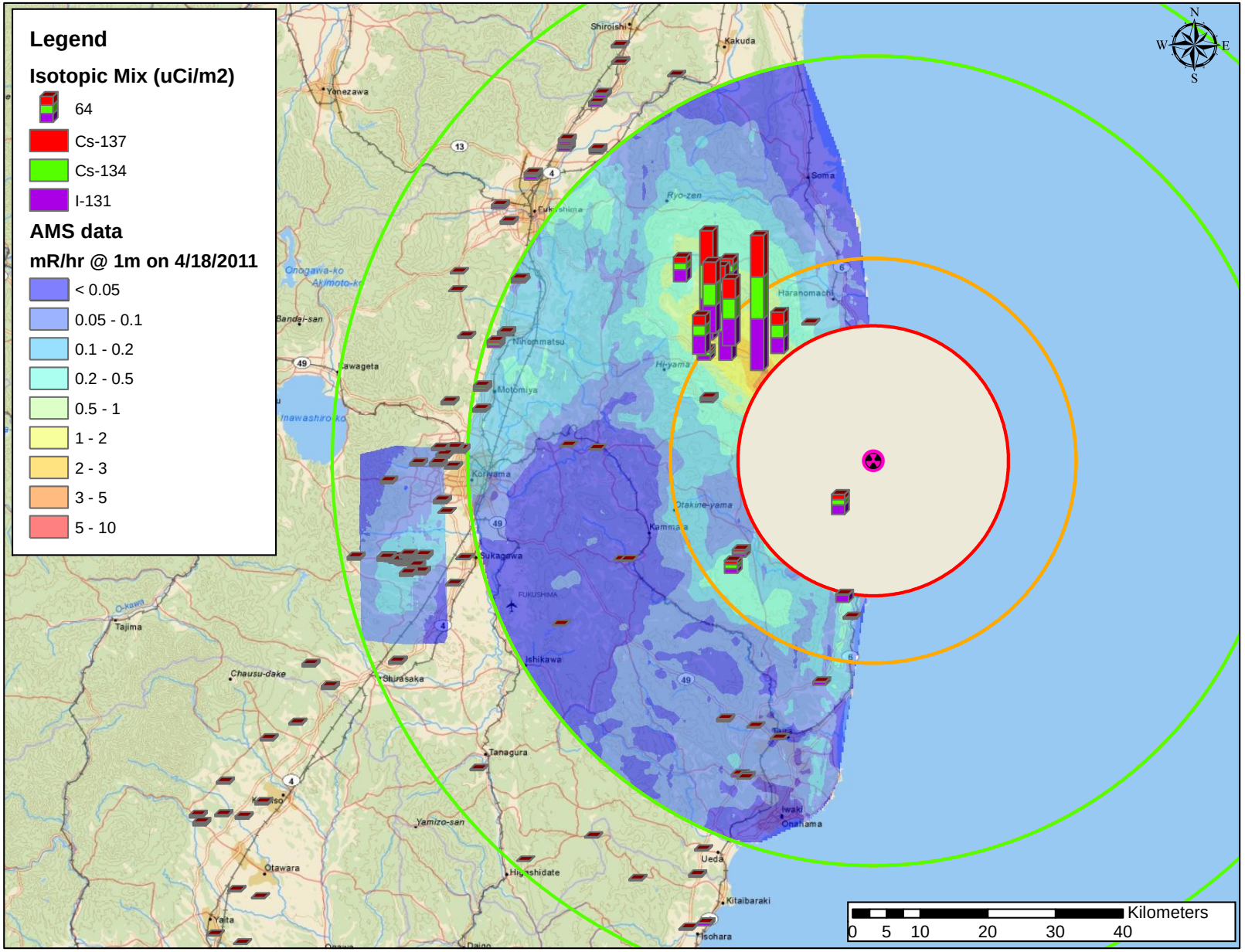




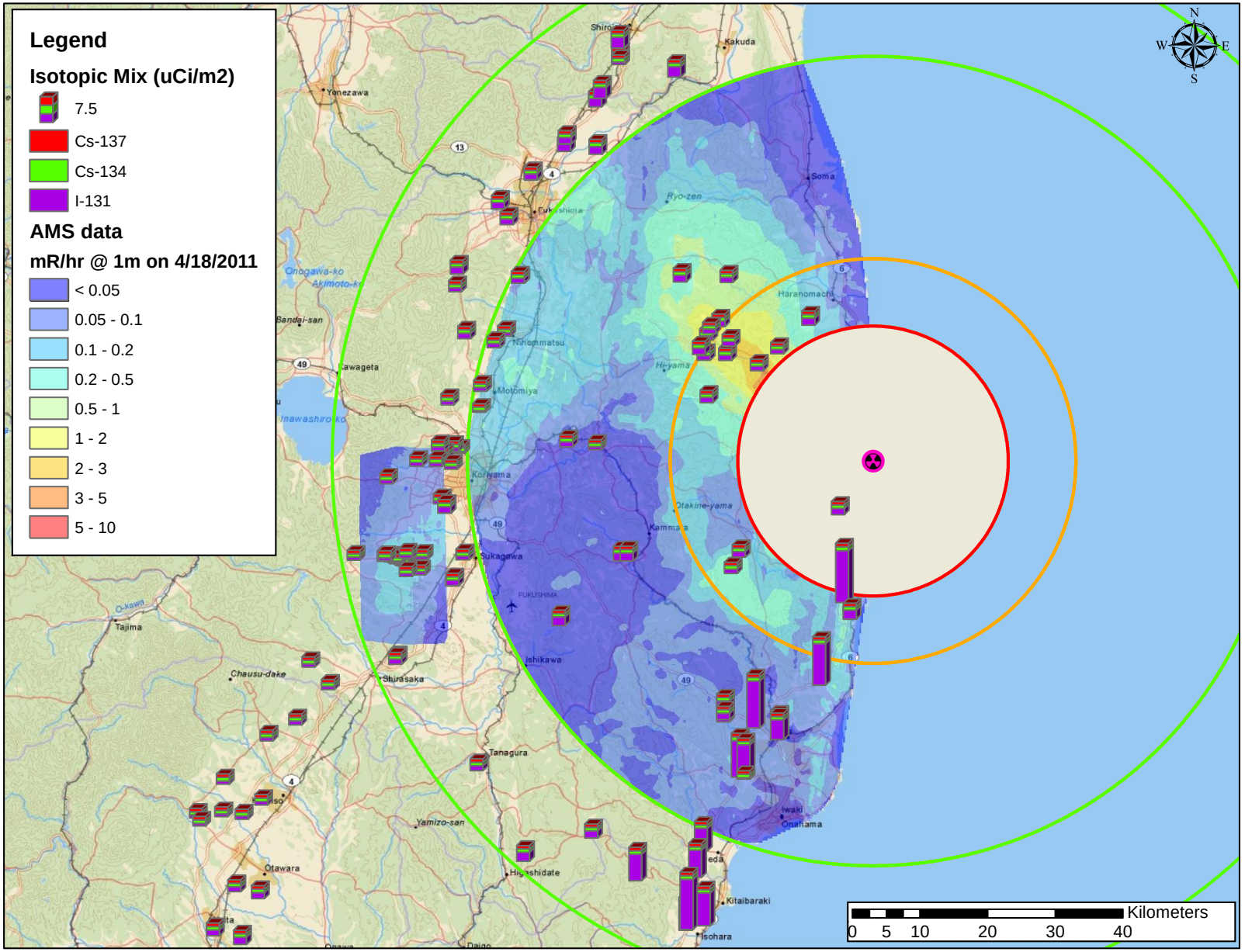
Uncertainties for *In Situ* Measurements

- Infinite plane, uniform deposition assumption
  - Surface roughness
  - Nearby obstructions
  - Deposition on grass and vegetation
- Surface deposition vs. permeation into ground
  - Exponential or uniform depth profile
  - Attenuation through ground
  - Soil and core samples
- Angular response of detector
  - Calibrated pads
  - Point source characterizations
  - Mathematical models (MCNP)

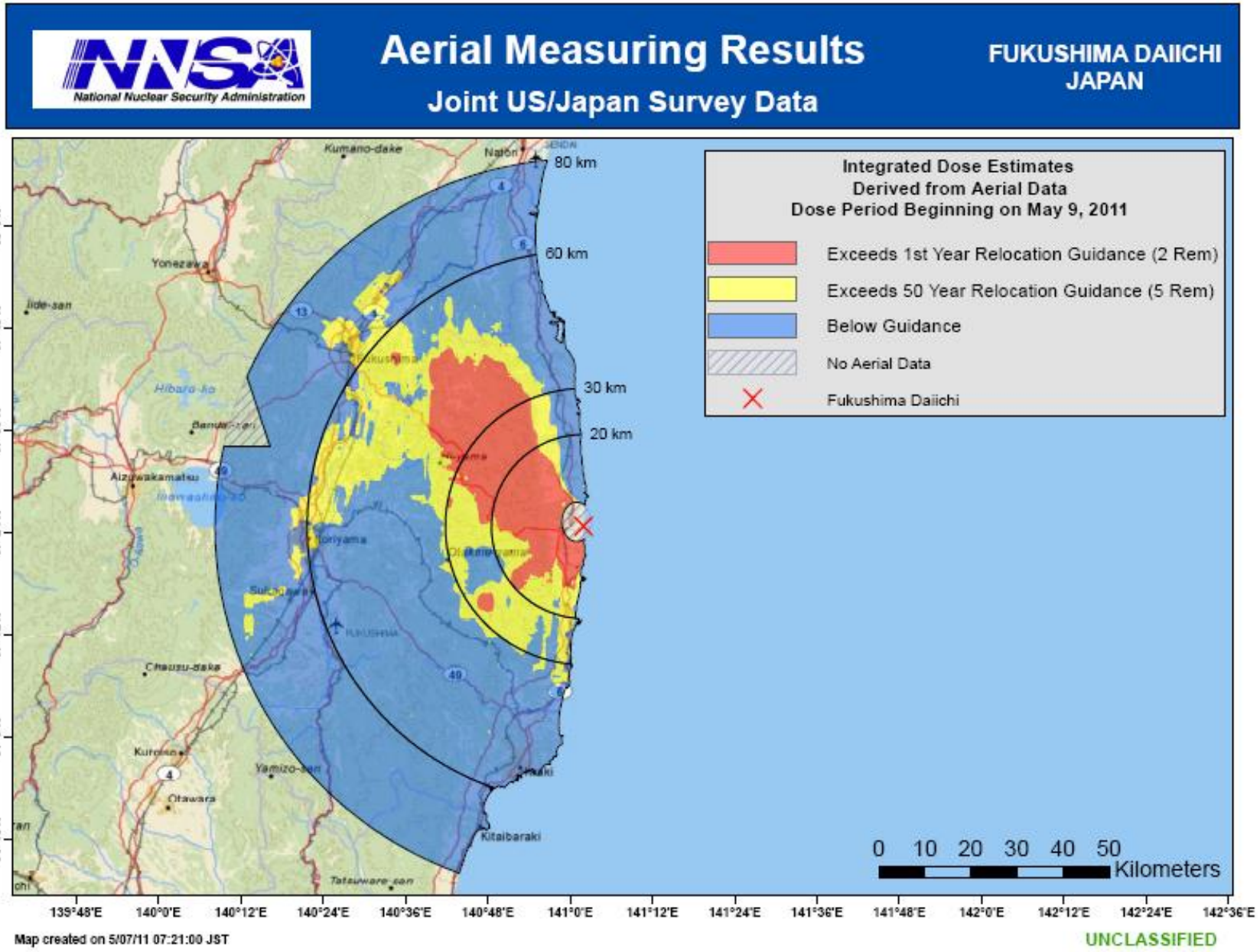
HPGe Results – Isotopic Concentration Corrected to 4/1/2011



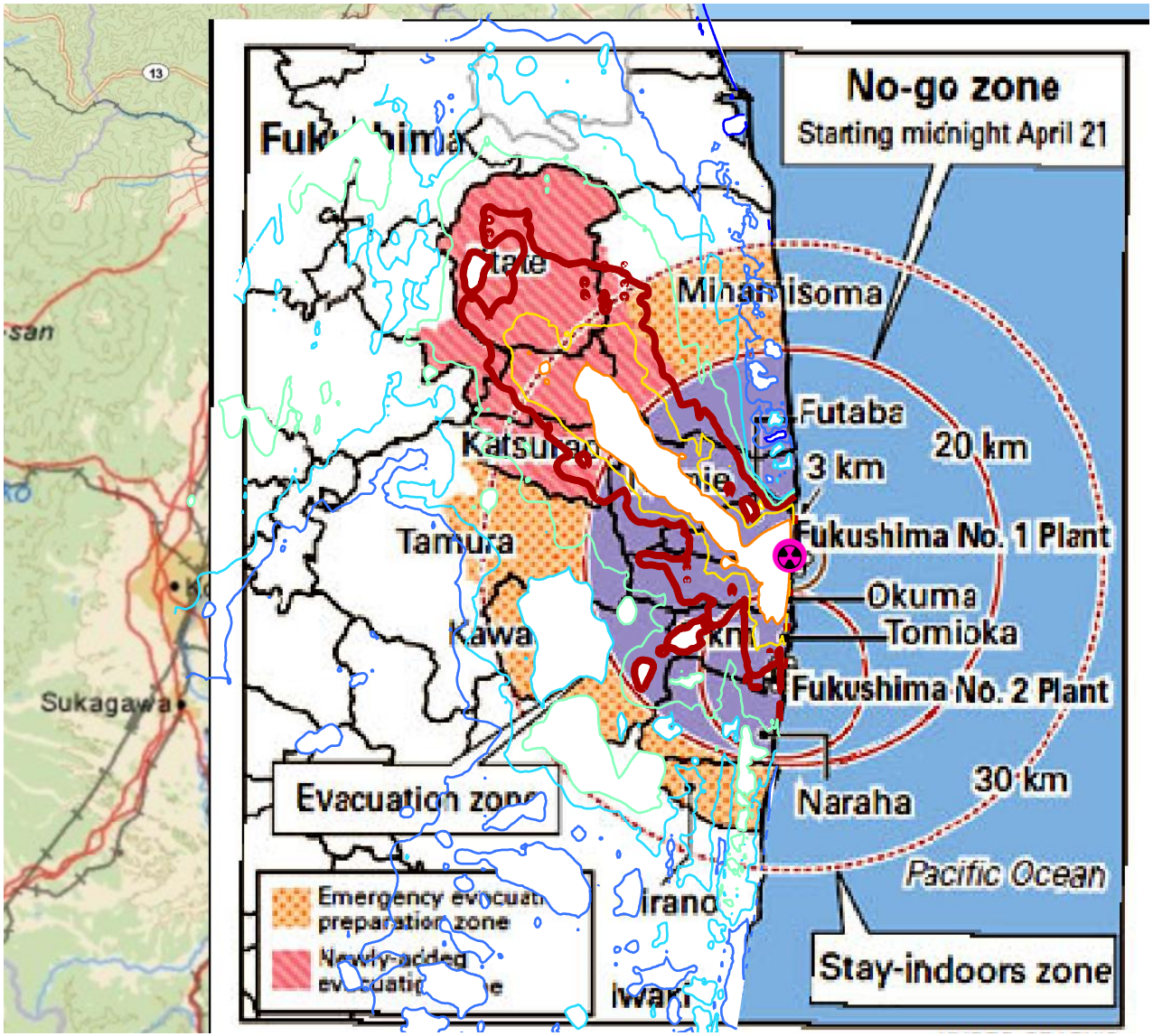
HPGe Results – Normalized to Cs-137



Projected Dose Estimates



Expanded Japanese Evacuation Zones

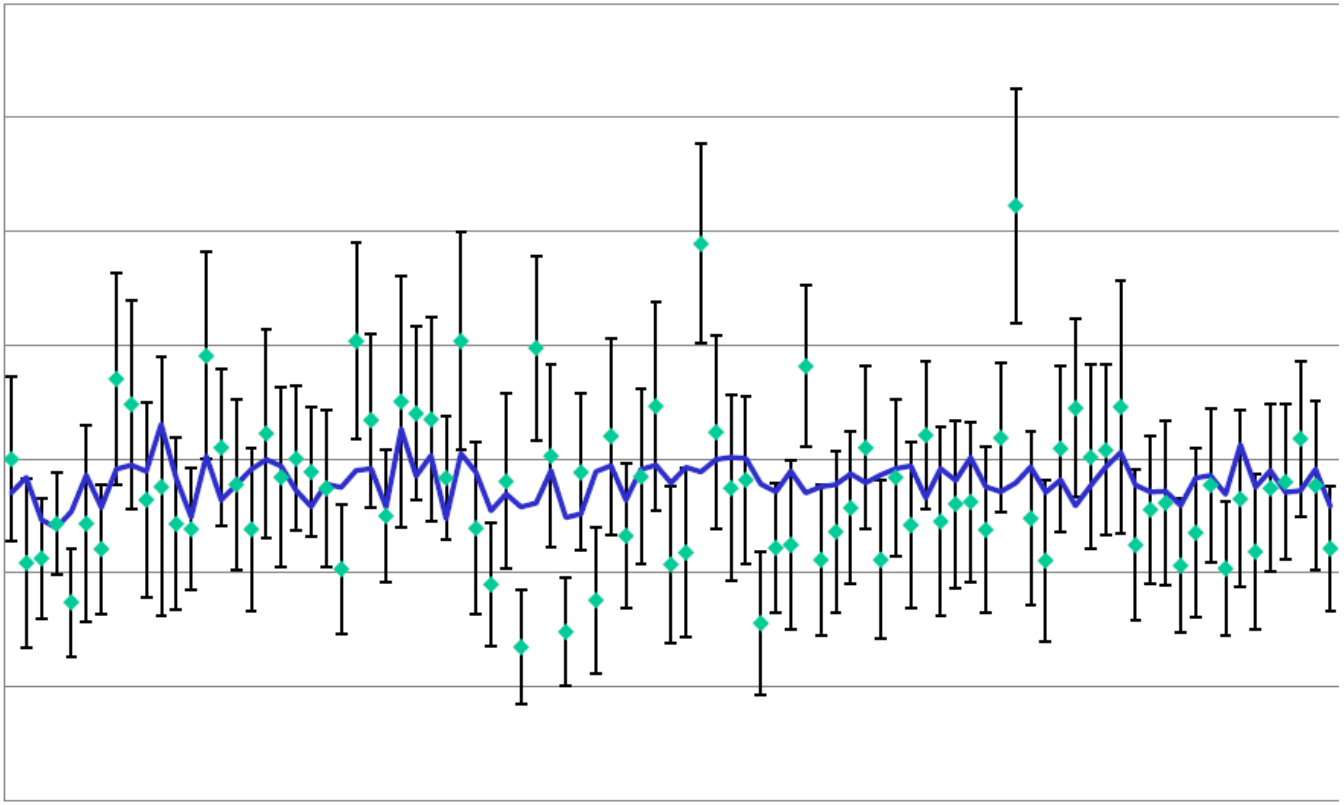


- Announced by GOJ around April 20th
- Effective May 1
- Based in large part on U.S. AMS and ground monitoring data

Soil sampling

Core Sampling

Total Sr Analysis



MDA

Sandia National Laboratories

Challenges:

- Sr-89/90 Analysis is time consuming, it requires several days to allow ingrowth as part of the analysis process.
- Activity on these samples was near detection levels and as a result the Sr to Cs ratios varied widely from 1:1 to 2000:1. The fact that they were all near detection level seemed to be causing this variability.

Monitoring Challenges

Roads to Nowhere?


Access Issues
立入禁止

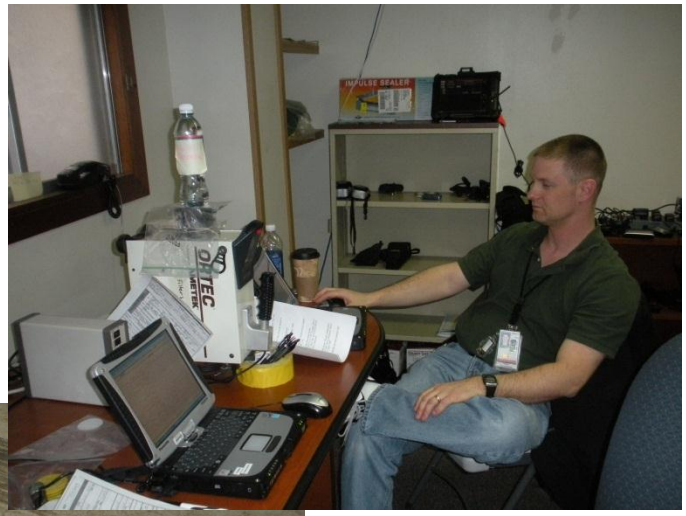

Inclement Weather


Public Areas
SOKKIA


Uncooperative Equipment
ORTEC

Sample Counting in Contaminated Environment

- Air filter, swipe, and soil samples
  - Lines from I-131, Cs-134, Cs-137 present in background spectra
  - Background varied significantly in early days



Monitoring Opportunities


Gracious Locals


Beautiful Countryside


New Cuisine

Luxurious Office Space

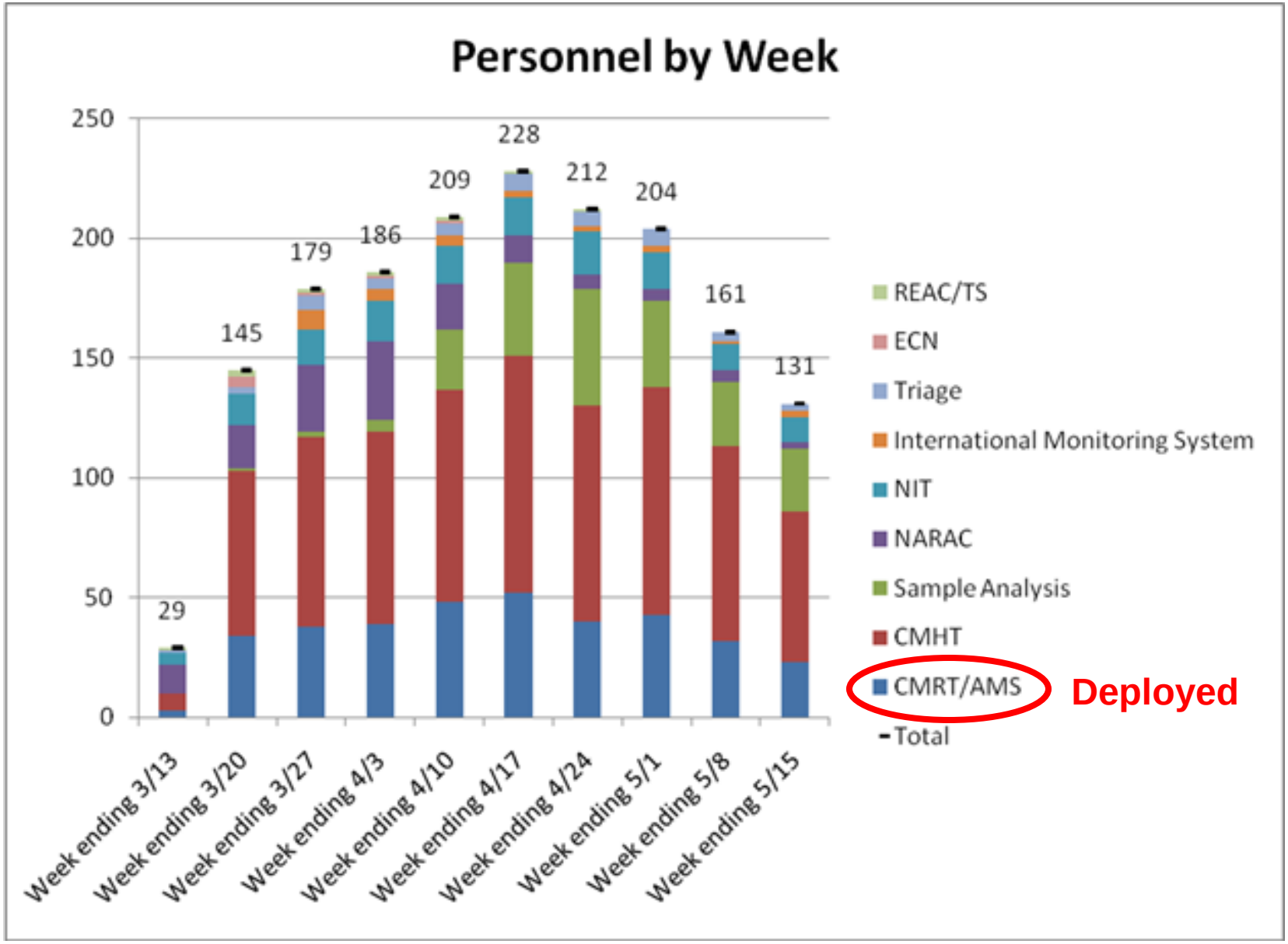
Interesting Guests


第五蔵王丸

Field Team Activity Successes

- DOE was able to perform on-the-fly analysis to deal with multiple ongoing releases, unknown source terms, challenging terrain as well as non-technical pressures.
- DOE Scientists developed customized products for U.S. military (data products, InField Monitoring System).
- DOE scientists embedded with Japanese scientists to create joint data products.

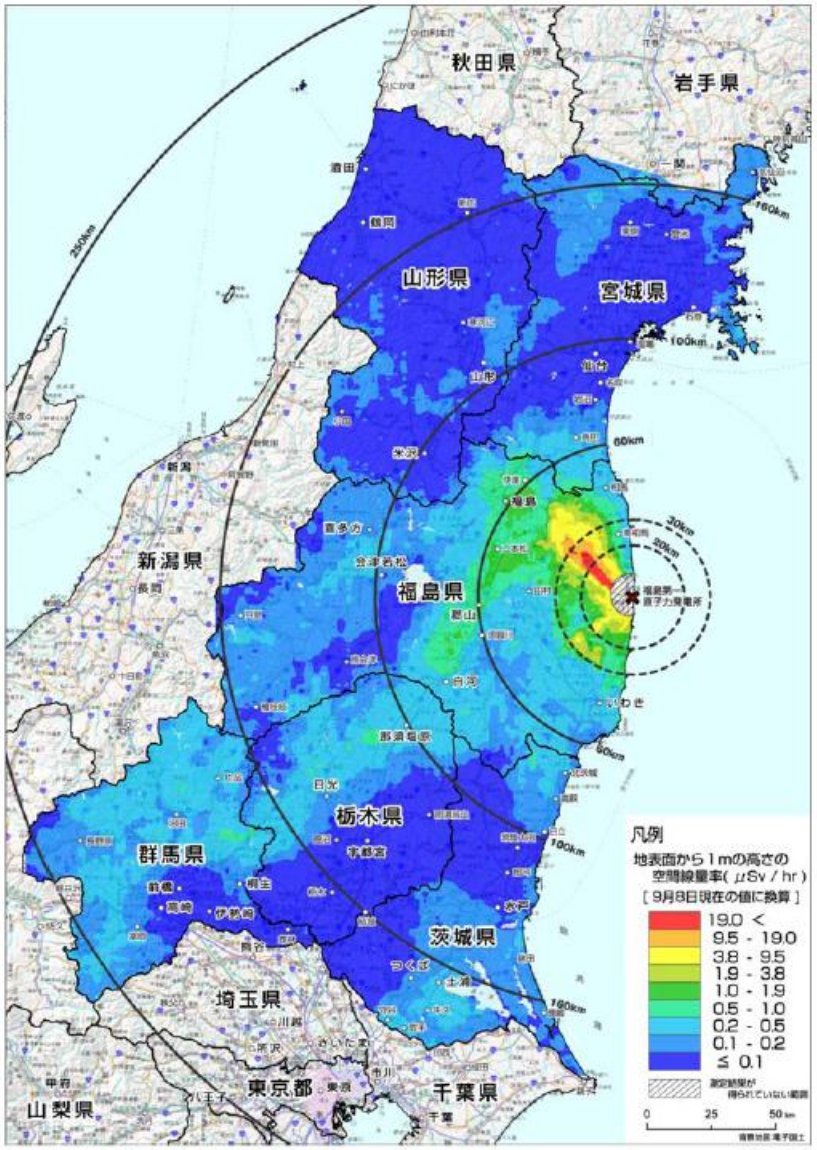
Response Personnel

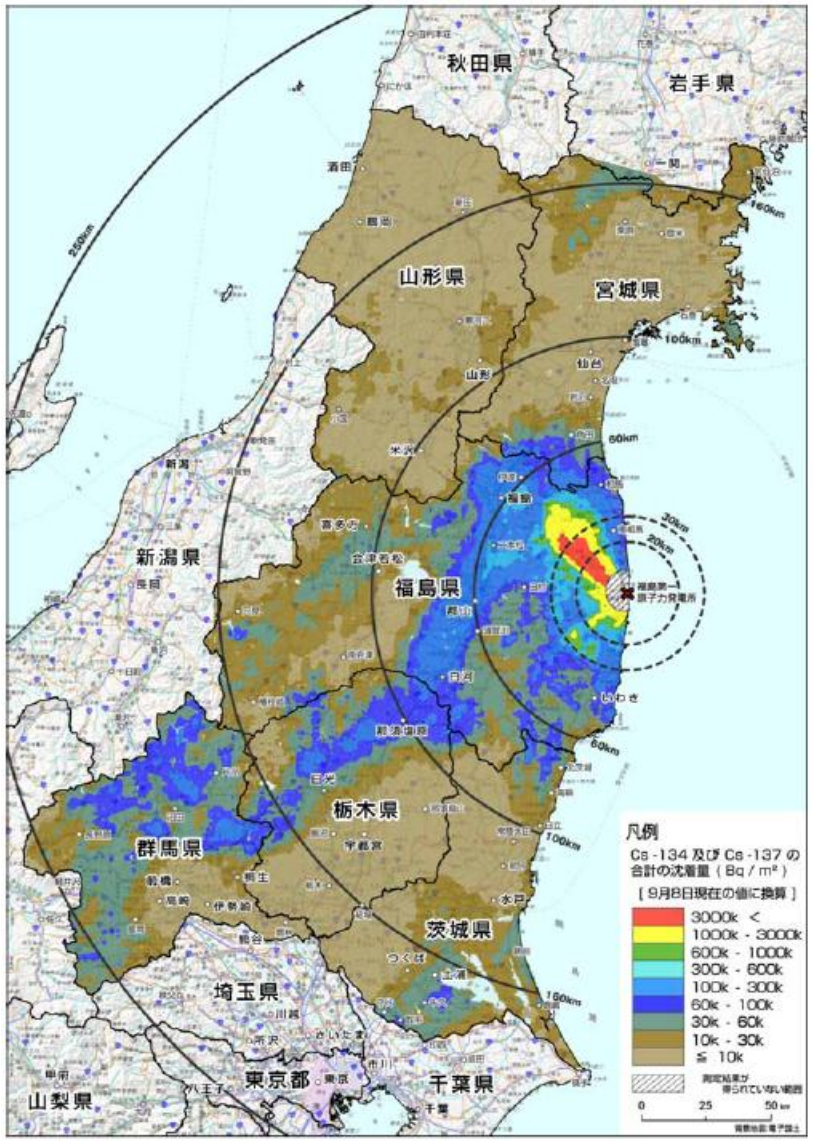


End State

- USFJ and Government of Japan to continue monitoring activities as needed
  - Japanese trained & equipped to fly DOE AMS equipment
  - Japanese equipped with an enhanced laboratory analysis capability
  - USFJ trained & equipped to fly contigency AMS
  - DOE continues to support Japanese and USFJ from Home Team

Recent Japanese Data



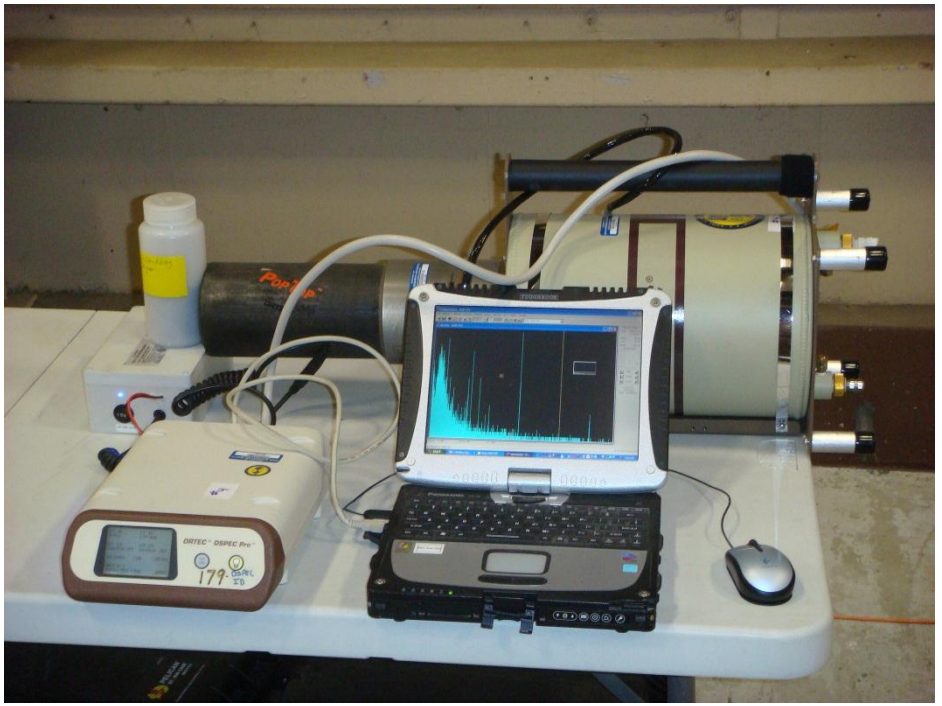


Questions?

Some Sources of Information

- DOE Blog
  - http://blog.energy.gov/content/situation-japan
- ANS Nuclear Café
  - http://ansnuclearcafe.org/
  - Click on the Fukushima tab
- Areva Presentation
  - http://physics.harvard.edu/~wilson/AREVA_Fukushima.ppt
  - Or Google “Areva Braun Fukushima”
- “Nuclear Boy” video
  - http://www.youtube.com/watch?v=5sakN2hSVxA


EMERGENCY PHONE


ORTEC DSPEC Pro


Survey Areas
FUKUSHIMA DAIICHI
JAPAN
Results 03/17 - 04/03/2011
Data from 4/03/2011
Overview Map
30 km
Official Use Only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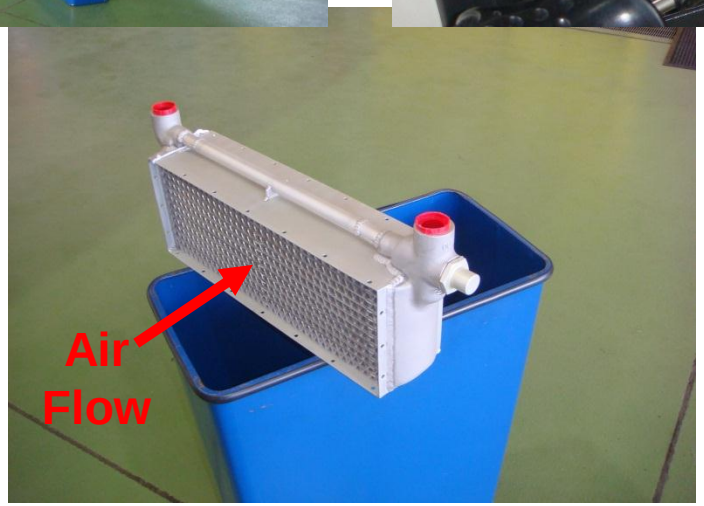
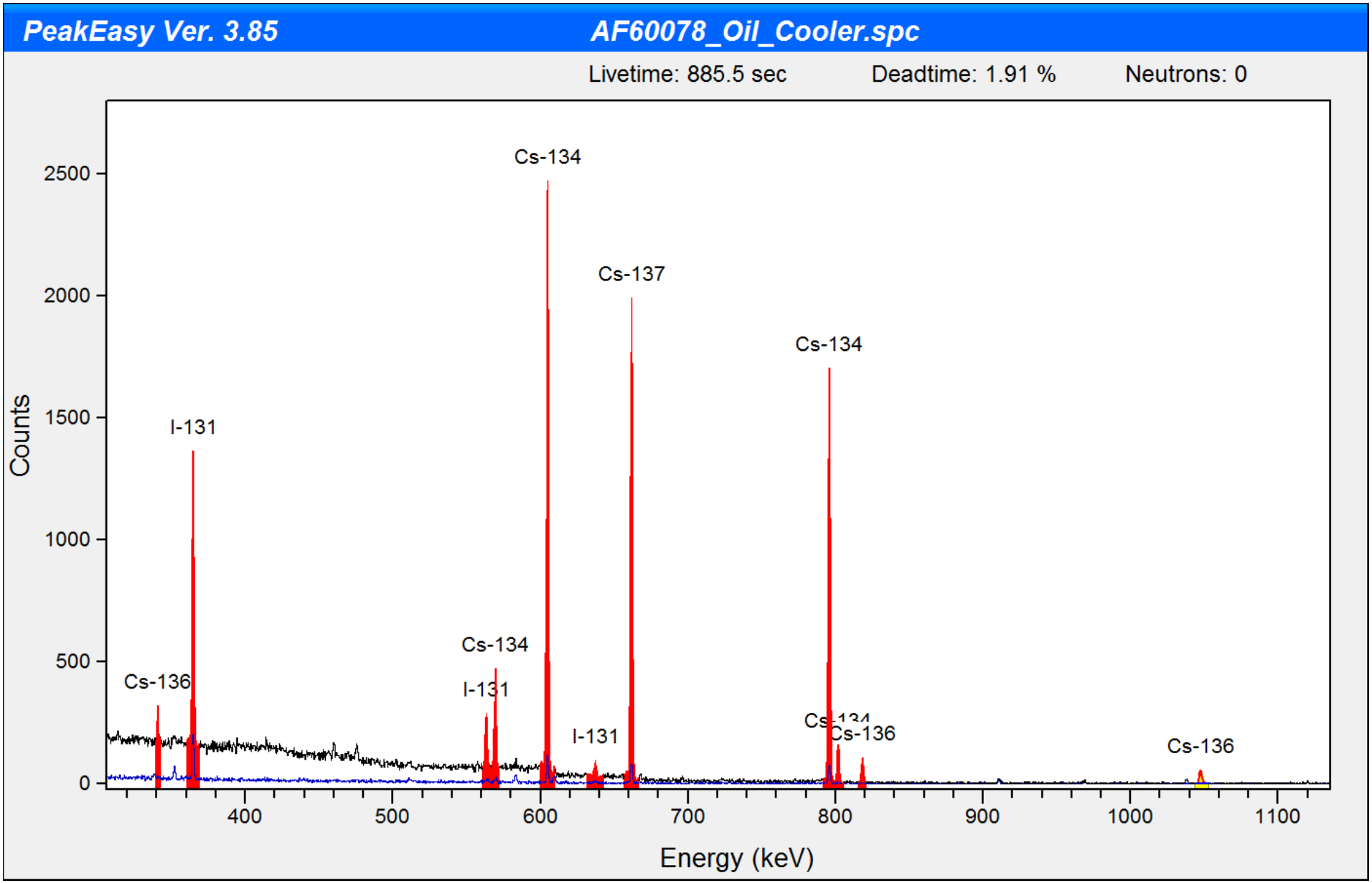
DANGER
RESCUE

USAF Oil-Cooler NDA Request

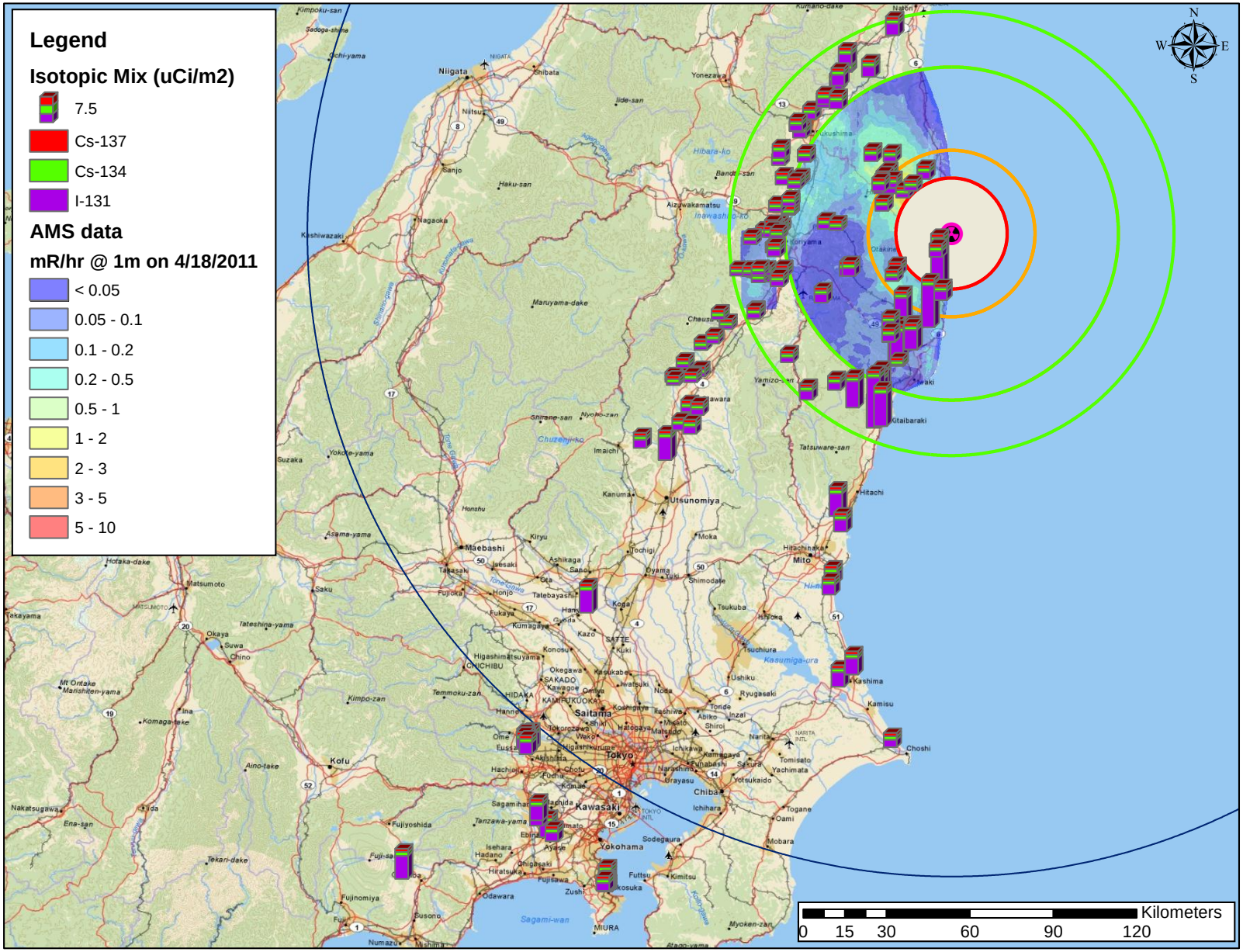
- Flight from Okinawa to Yokota
- Concern for ground crew safety
- Request for isotope ID and activity



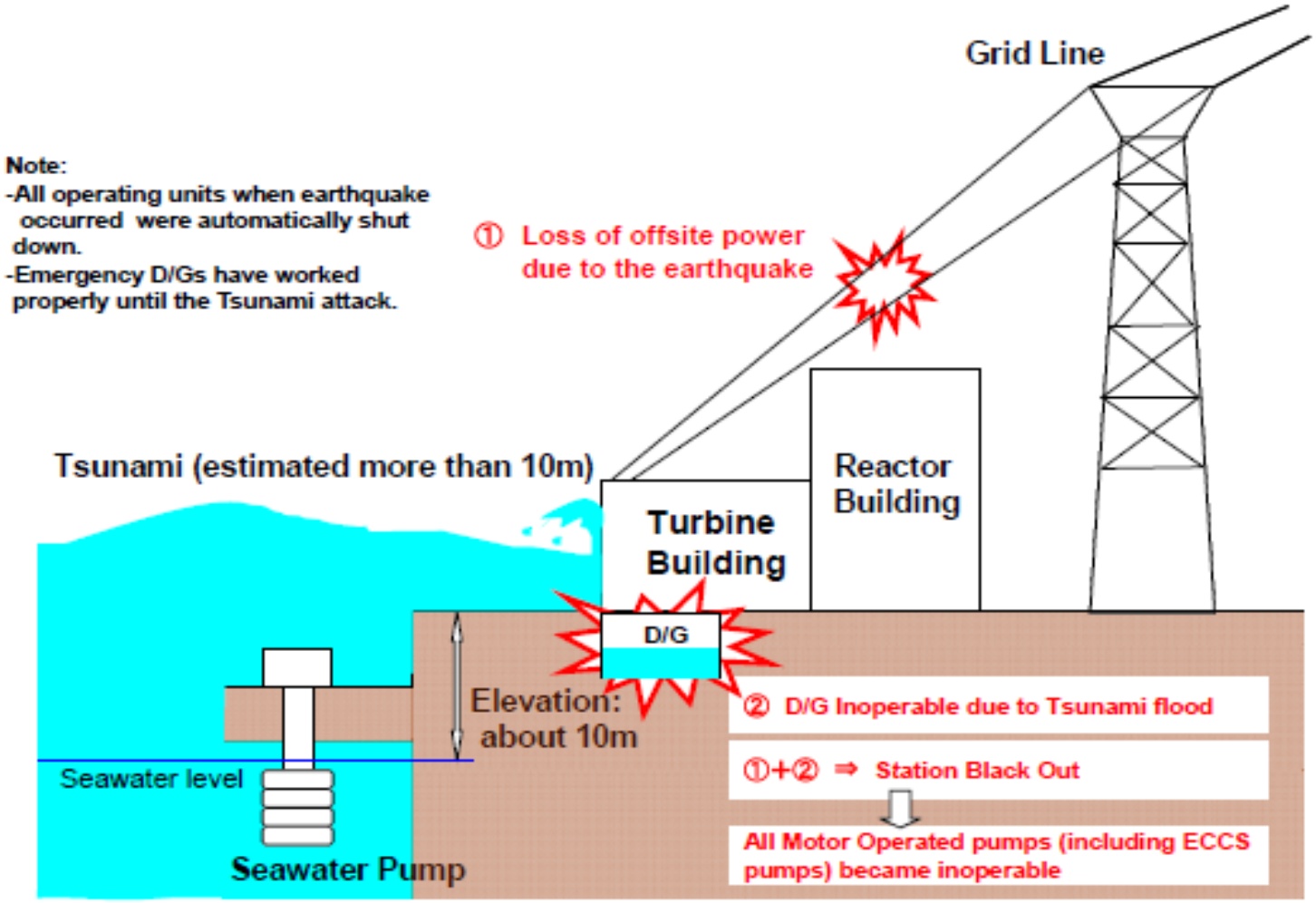


I-131 (0.2 uCi), Cs-134,137 (0.8 uCi), Cs-136 (0.05 uCi)

HPGe Results – Normalized to Cs-137



Root Cause of Damage



Source: Nuclear and Industrial Safety Agency (NISA)