平成24年度原子力災害影響調査等事業
（事故初期のヨウ素等短半減期核種による内部被ばく線量評価調査）
第3回専門委員会議事次第

1. 日時： 平成25年1月8日(火)14:00～17:00

2. 場所： 東京八重洲あすか会議室(303C室)

3. 議題
   (1) 第2回国際シンポジウムについて
   (2) 本事業の検討結果の概要について
       - 大気拡散シミュレーション
       - 初期内部被ばく線量再構築(中間報告)
   (3) その他

4. 配布資料
   資料③－1 第2回国際シンポジウムプログラム
   資料③－2 「大気拡散シミュレーションによる時系列大気中放射性物質濃度マップの整備」国際シンポジウム報告案
   資料③－3 Reconstruction of early internal doses in Fukushima NPS accident

資料③－１

第２回国際シンポジウム
東京電力福島第一原子力発電所事故における初期内部被ばく線量の再構築

日時：平成25年1月27日（日）
会場：東京国際交流会館　プラザ平成３階　国際交流会議場

9:20　～　受付開始、開場

開会式

10:00 ～ 10:15　開会挨拶
本シンポジウムの概要

セッション１　東電福島第一原発事故による環境影響

10:15 ～ 10:40　福島周辺の放射性核種沈着量の分布と経時変化
斎藤　公明（日本原子力研究開発機構）

セッション２　放射線影響に関する最新知見

10:40 ～ 11:05　放射線リスク評価における線量率効果　酒井　一夫（放射線医学総合研究所）

11:05 ～ 11:20　休憩

セッション３　海外における線量再構築の経験と教訓

11:20 ～ 11:50　チェルノブイリ事故における線量再構築の経験
Valerii Stepanenko (MRRC Russia)

11:50 ～ 12:20　東電福島第一原発事故における線量再構築への提案
Andre Bouville (NCI USA)

12:20 ～ 13:20　休憩（昼食）

セッション４　内部被ばく線量測定の実際

13:20 ～ 13:45　福島住民のWBCによる内部被ばく線量評価　百瀬 琢磨（日本原子力研究開発機構）

13:45 ～ 14:10　ホールボディカウンタによる放射性セシウム放射能を用いた放射性ヨウ素(I-131)の甲状腺被ばく線量の推定　床次　眞司（弘前大学）

14:10 ～ 14:25　在日ロシア人の甲状腺線量測定　Sergey Shinkarev (BFMBC Russia)

セッション５　放射性物質の大気拡散シミュレーション

14:25 ～ 14:50　大気拡散シミュレーションによる福島第一原子力発電所から放出された放射性物質の時空間分布再構築　永井　晴康(日本原子力研究開発機構)

14:50 ～ 15:00　休憩

セッション６　初期内部被ばく線量推計

15:00 ～ 15:45　東電福島第一原発事故における初期内部被ばく線量の再構築
栗原　治（放射線医学総合研究所）

15:50 ～ 17:15　討論

閉会式

17:20 ～ 17:30　閉会挨拶

資料⑬-2]

平成25年1月8日内部被ばく線量評価調査専門委員会

「大気拡散シミュレーションによる時系列大気中放射性物質濃度マップの整備」国際シンポジウム報告案

大気拡散シミュレーションによる福島第一原子力発電所から放出された放射性物質の時空間分布再構築

原子力機構　永井晴康、堅田元喜、太田雅和、伊奈拓也、掛札豊和、遠藤章

目的と内容

【目的】

- 東京電力福島第一原子力発電所の事故時に放出された放射性物質による福島県等の住民の健康リスク評価を行うための基礎データとして、被ばく線量の把握を行う。
- ヨウ素等の短半減期核種による事故初期段階における内部被ばく線量については、現時点では実測に基づく評価が困難なため、大気拡散計算により時系列大気中放射性物質濃度マップを構築し、行動パターンと組み合わせた推計に用いる。

【実施内容】

- ヨウ素等の短半減期核種の放出率の時系列変化、放出高さ等の放出源条件について、公表情報や文献の調査に基づき整備する。
- 気象モデルによる事故時の気象場再現計算と、大気拡散モデルによる上記放出源条件を用いた放射性物質の移流、拡散、沈着計算を実施する。
- 大気中核種濃度、地表沈着量、及び空間線量率の計算値とモニタリングデータの比較により、計算結果の妥当性確認及び誤差評価を行う。
- 大気拡散計算による核種毎の大気中濃度分布を、水平方向の所定の間隔、毎時刻で出力し、時系列大気中放射性物質濃度マップを作成する。

大気拡散シミュレーションモデル

(1)WSPEEDI-IIの構成

MM5(PSU/NCAR開発)

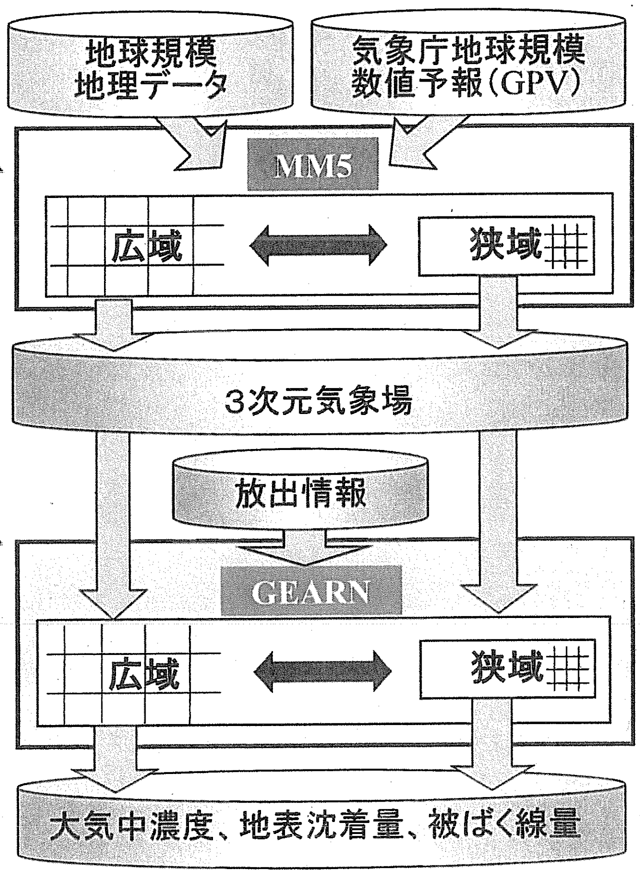
領域気象力学モデル

- 雲・降水、大気放射等の各種物理過程を考慮
- 気流、乱れ、降雨、雲量等の気象変数の予測

GEARN(原子力機構開発)

ラグランジュ型粒子拡散モデル

- 放射性核種の移流・拡散・沈着・崩壊を考慮
- 大気中濃度、地表沈着量、被ばく線量の予測



参考文献:寺田、他:緊急時環境線量情報予測システム(世界版)WSPEEDI第2版の開発,日本原子力学会和文論文誌, 7[3], 257-267 (2008).

大気拡散シミュレーションモデル

(2)WSPEEDI-IIの福島第一原発事故への適用

【放出量推定】 原子力安全委員会への協力

- ■ 暫定放出量推定発表:原子力安全委員会発表(4月12日、5月12日)
  原子力学会欧文誌 M. Chino, et al., 2011: J. Nucl. Sci. Technol., 48,1129–1134
- ■ 3月15日までの放出量の再評価:原子力安全委員会発表(8月22日)
  (http://www.nsc.go.jp/anzen/shidai/genan2011/genan063/siryo5.pdf)
  G. Katata, et al., 2012: J. Environ. Radioactiv., 109, 103-113

【大気拡散解析】

- ■ 局地詳細計算によるプラント北西地域の線量上昇プロセスを解析
  ⇒ 6月13日プレス発表
  (http://www.jaea.go.jp/02/press2011/p11061302/index.html)
  G. Katata, et al., 2012: J. Environ. Radioactiv., 111, 2-12
- ■ 事故発生後2ヶ月間の日本全国の被ばく線量を暫定的に試算
  ⇒ 6月15日原子力機構HP技術解説
  (http://www.jaea.go.jp/jishin/kaisetsu03/kaisetsu03.htm)
- ■ 東日本域の大気降下量の試算と推定放出量の確認+沈着過程の解析
  ⇒ 8月31日厚労省プレス発表、9月6日原子力機構HP技術解説
  (http://nsed.jaea.go.jp/fukushima/data/20110906.pdf)
  H. Terada, et al., 2012: J. Environ. Radioactiv., 112, 141-154

放出源情報の検討

■対象核種
- 線量寄与率が大きい核種：I-131、I-133、Te-132、Cs-137
- Cs-137については、沈着量データとの比較に利用

■放出率時間変化
- JAEAのI-131、Cs-137の推定結果（Terada et al. 2012）が現時点で最も妥当
- 他の短半減期核種（I-133、Te-132）は、モニタリング等の組成比から決定

→　放出率のコントロールケース設定

■他の放出源推定結果の適用
- 時間変化があるStohl et al. 2012の推定結果
- 炉内解析による推定結果（準備中）

■JAEA放出源情報の不確実性の評価
- 名古屋大の推定結果利用：ファクター3程度（陸上の測定値が得られた期間）
- 放出率コントロールケースの各分割期間（放出率一定）の放出率を変えて全体への影響の度合いを評価：不確実性の影響が大きい期間を抽出

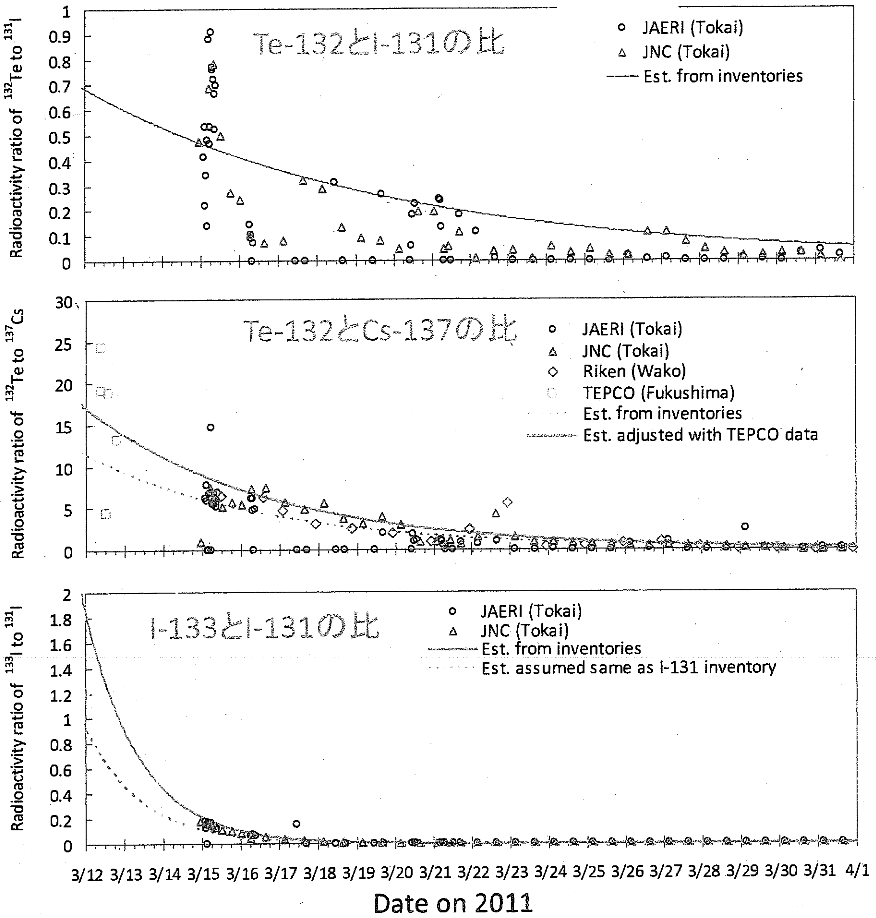
短半減期の放射性核種の放射能比率推定

- I-131, Cs-134, Cs-137の環境モニタリングデータは多く、シミュレーションによる逆推定が行われている（e.g., Chino et al. 2012, Katata et al. 2012, Terada et al. 2012）
- 一方、I-132, Te-132, I-133などの相対的に半減期が短い核種のデータは限られており、逆推定することは困難である
- 数少ない環境モニタリングデータと、減衰係数や推定インベントリから、放射能比率を推定する必要がある

Radionuclide	State in atmosphere	Half-life	Boiling point (℃)	Inventory (PBq)*	Environmental data source
I-131	Gas/aerosol	8.0 day	180	6.02E+6	Large
I-132	Gas/aerosol	2.3 hour	180	8.85E+6	Limited
Te-132	Gas/aerosol	3.2 day	1400	8.68E+6	Limited
I-133	Gas/aerosol	21.0 hour	180	1.26E+7	Limited
Cs-137	Aerosol	30.0 year	670	6.98E+5	Large
Cs-134	Aerosol	2.1 year	670	7.18E+5	Large

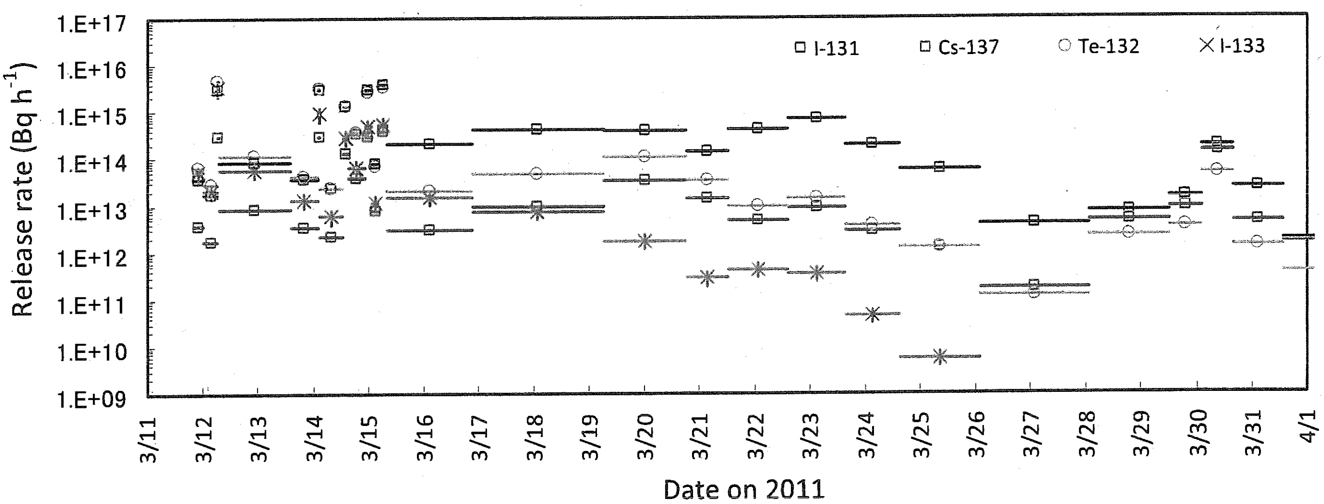
*The total inventories at Unit 1 to 3 of Fukushima Dai-ichi Nuclear Power Plant (Nishihara et al. 2012)

放射能比率の推定値と国内の観測値との比較



- Te-132は、I-131に比べてCs-137との相関が高かった（沸点がヨウ素より高いためか？）
- インベントリによる推定結果を東電による事故初期の観測値（$Te^{132}/Cs^{137} \cong 20$）で補正し、$Te^{132}/Cs^{137}$の変化傾向を再現した
- I^{133}/I^{131}の濃度比率データは、I^{131}の1～2倍のI^{133}インベントリを用いた推定値の範囲に収まった

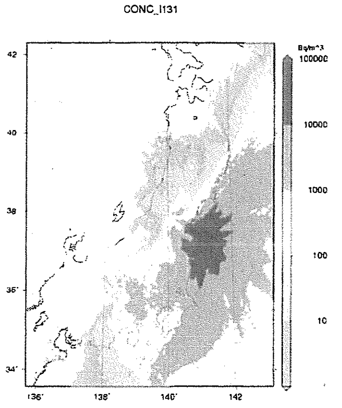
放出率コントロールケースの時間的推移



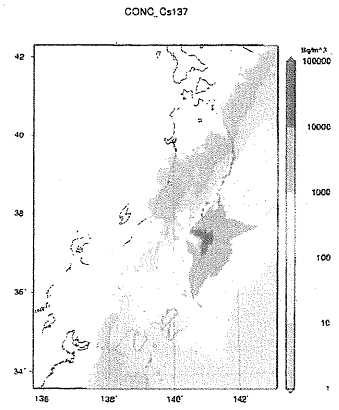
*I-133の縦エラーバー：I^{131}に対するI^{133}のインベントリ比を1～2に変化させた場合の放出率の変動幅

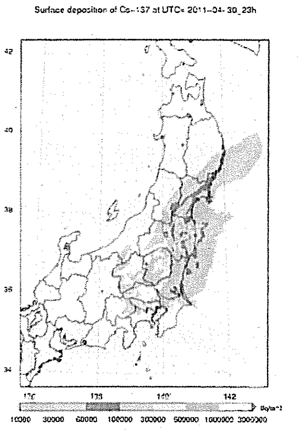
放出率コントロールケースによる期間積算濃度分布

I-131

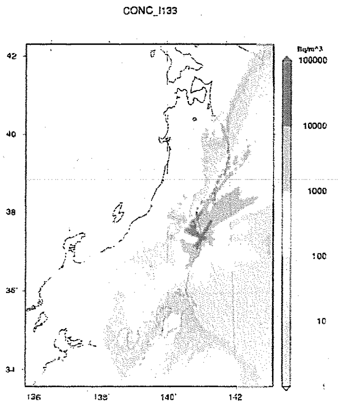


Cs-137

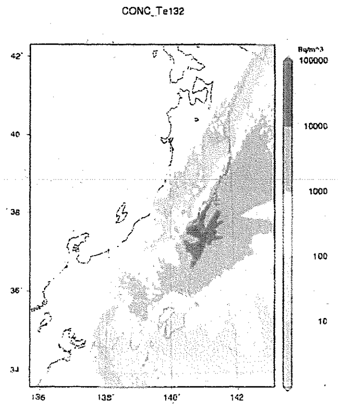




I-133

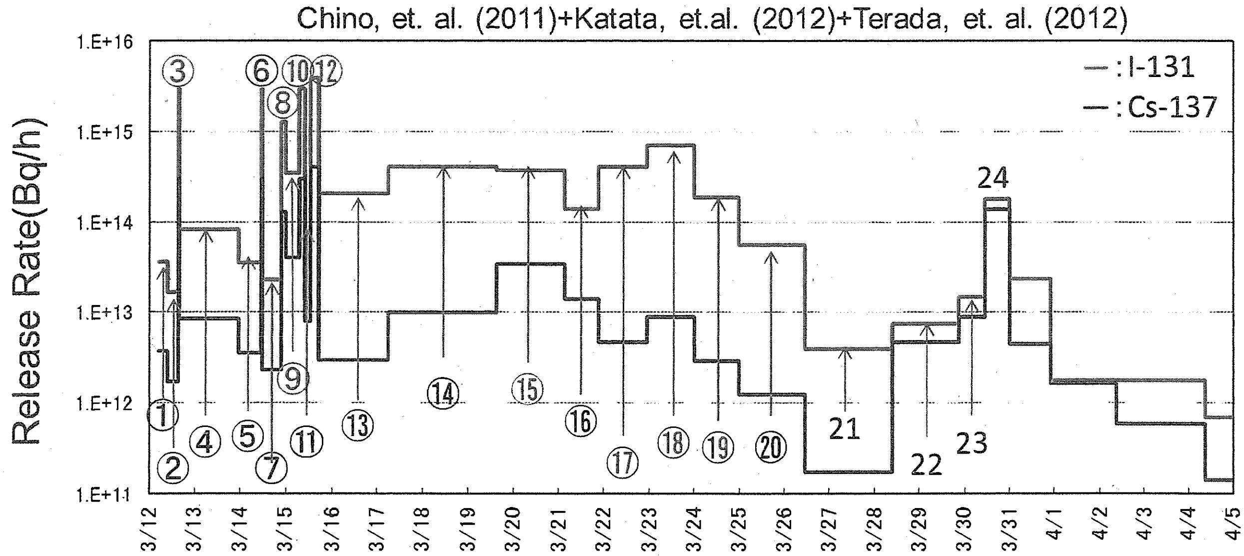


Te-132



<u>Cs-137沈着量分布</u>
積算濃度分布と大きく異なる(湿性沈着過程の影響)
⇩
沈着量分布から簡易に濃度分布を求めることはできない

放出期間ごとの不確実性の影響



- 赤字の期間：各放出率一定の期間1～24について、1つの期間だけの放出率を変えた場合に、期間全体の積算濃度がどの程度変わるかを評価し、被ばく線量評価上放出率の不確実性の影響が大きい期間を抽出。
- 海側に流れて測定データが得られなかったため放出率推定の不確実性が大きいと考えられている期間(④～⑦、⑬～⑭)は、被ばく線量評価上放出率の不確実性の影響はほとんどない。

⇒　赤字の期間のみ放出率をファクター3で変えて影響を評価

気象計算

気象モデルMM5の計算条件

■計算領域：東西690km×南北960km×鉛直10km
・半径250kmの評価対象範囲の陸地を含む
・評価エリアへのプルームの再流入も考慮

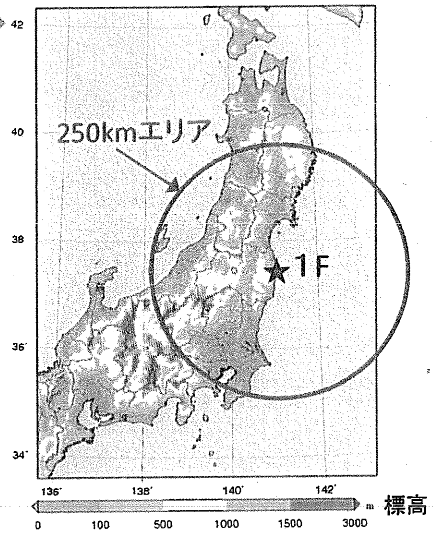
■空間分解能：3kmメッシュ

■計算期間：2011年3月11日～4月30日24時
既存の計算結果を有効活用

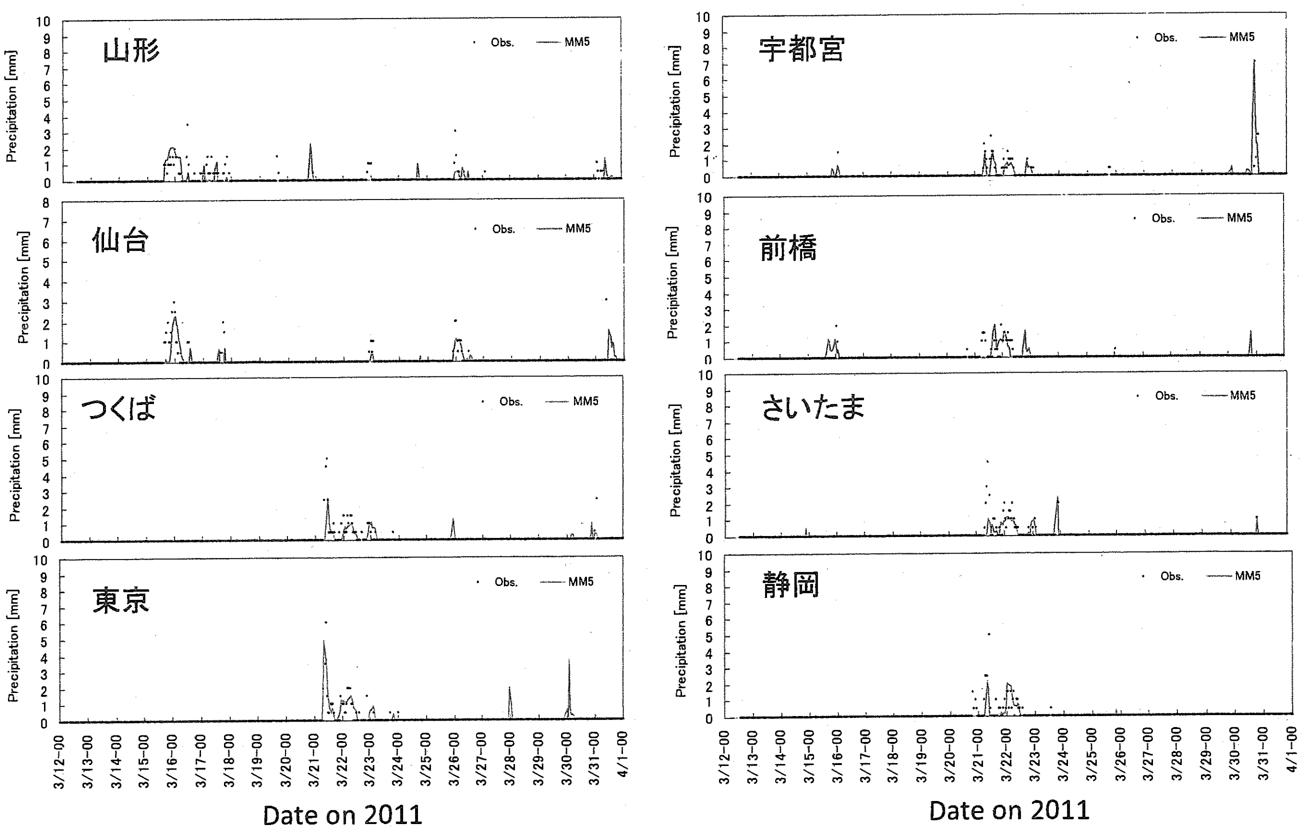
■気象予測の初期・境界条件
・気象庁数値予報格子点値GPV（MSM）：3h間隔
・気象庁アメダス、福島第一原発（1F）及び第二原発における観測データの同化により予測値を修正

■予測結果の確認
・気象観測データ（アメダス、レーダーアメダス解析）との比較により気象場再現性を確認

計算領域



2011年3月のWSPEEDIの降水量の再現性



拡散計算

拡散モデルGEARNの計算条件

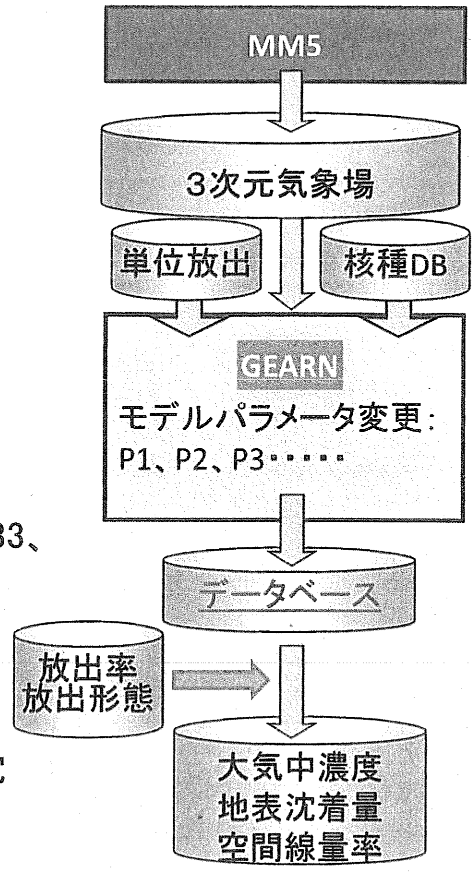
■計算領域：東西690km×南北960km×鉛直10km
気象モデルMM5と同じ領域

■空間分解能：3kmメッシュ

■計算期間：2011年3月11日～4月30日24時
放出開始時刻を考慮し計算開始時刻を設定

■放出源条件
・放出源検討結果から、評価対象核種（I-131、I-133、Te-132、Cs-137）の放出率を設定
・単位放出計算によりデータベース作成
⇒　放出源条件を変更可能（期間分割は固定）

■モデルパラメータの感度解析
・主要拡散プロセスについて、モデルパラメータ（沈着過程）を変更する感度解析により不確実性評価
⇒　粒子状、ガス状の湿性沈着への影響評価
　放出源情報と同様にデータベース作成



予測結果の感度解析

WSPEEDIにおける乾性沈着パラメータ

$$\frac{dq_n}{dt} = -kv_d q_n$$

q_n: 粒子nの放射能量, v_d: 乾性沈着速度, k: 寄与率（地上からの距離等の関数）

Radionuclides	Deposition velocity, v_d (cm s^{-1})	Particle diameter (μm)	Land surface	Reference
Gaseous elemental iodine	0.6	–	Grass	Baklanov and Sorensen (2001)
	0.1 – 2.0	–	Grass	Sehmel (1980)
Particulate iodine	0.1	0.48	Grass	Baklanov and Sorensen (2001)
Cs-137	0.05	–	Grass	Baklanov (1999), Garland (2001)
	0.1	0.68	Grass	Baklanov and Sorensen (2001)
	0.04 – 0.5	–	Grass	Sehmel (1980)
Cs-134	0.12	0.59	Grass	Baklanov and Sorensen (2001)
Other aerosols	0.2	Accumulation mode	Grass	Raes et al. (1991)

文献値に基づき、以下のようにv_dを設定する：
・ガス状放射性ヨウ素：0.6 cm s^{-1}
・粒子状放射性ヨウ素・セシウム：0.1 cm s^{-1}
＊沈着速度の大きい森林地帯では、v_dを5倍にする (Katata et al. 2012; Garland 2001)

WSPEEDIにおける湿性沈着パラメータ

$$\frac{dq_n}{dt} = -\Lambda q_n \qquad \Lambda = \alpha P_r^{\beta}$$

Λ: 洗浄係数, P_r: 降水強度, α, β: 観測に基づくパラメータ

Radionuclides	α	β	Particle diameter (μm)	Reference
Gaseous elemental iodine	8.0×10^{-5}	0.6	–	Brenk and Vogt (1981)
	8.2×10^{-5}	0.6	–	Belot et al. (1988), Caput et al. (1993)
Particulate I-131	7.0×10^{-5}	0.69	–	Jylhä (1991)
Particulate I-133	1.6×10^{-5}	0.5	–	Jylhä (1991)
Particulate Cs-137	3.4×10^{-5}	0.59	–	Jylhä (1991)
Particulate Cs-134	2.8×10^{-5}	0.5	–	Jylhä (1991)
Aerosols	1.2×10^{-4}	0.5	1.0	Brenk and Vogt (1981)
	4.0×10^{-5}	1.0	< 1.0	Belot et al. (1988), Caput et al. (1993)

文献値に基づき、以下のようにα, βを設定する:
- ガス状放射性ヨウ素: (α, β) = (8.0×10^{-5}, 0.6)
- 粒子状放射性ヨウ素・セシウム: (α, β) = (3.0×10^{-5}〜1.2×10^{-4}, 0.5〜1.0)

＊洗浄率の小さい雪では、洗浄係数Λを1/10にする (Hongist 1998; Mayron and Ryall 1996)

WSPEEDI沈着パラメータの設定

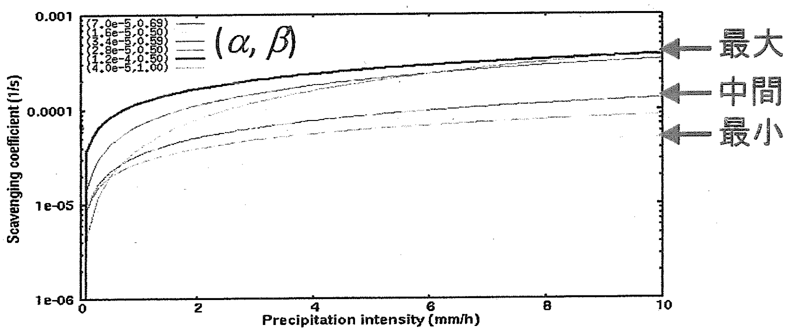
- 乾性沈着: $\frac{dq_n}{dt} = -kv_d q_n$
- 湿性沈着: $\frac{dq_n}{dt} = -\Lambda q_n \qquad \Lambda = \alpha P_r^{\beta}$

Radionuclides	v_d (cm s^{-1})	α	β	
Gaseous iodine	0.6	8.0×10^{-5}	0.60	
Particulate iodine and cesium	0.1	1.2×10^{-4}	0.50	← 最大
	0.1	3.4×10^{-5}	0.59	← 中間
	0.1	1.6×10^{-5}	0.50	← 最小

ガス状のみのケース、粒子状のみ3ケースのデータベース作成

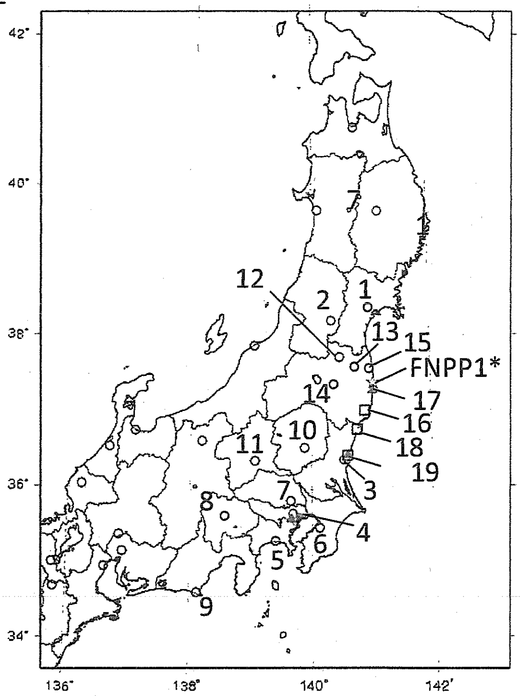
↓

各ケースの放出率を調整して結合することによりガス状と粒子状の割合を任意に設定可能



予測結果の評価：環境モニタリングデータ

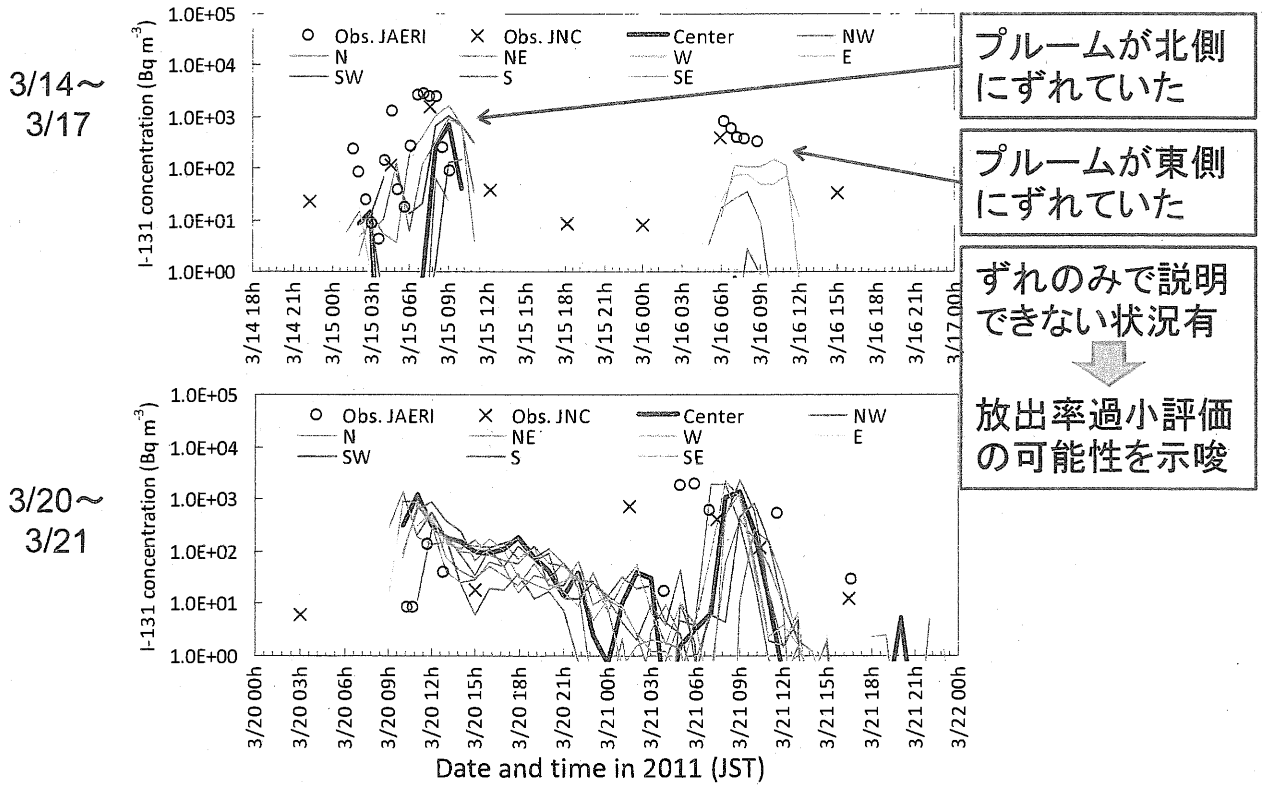
No.	Monitoring data	Sampling sites	Prefectures	Data sources
1	Air dose rate	Sendai	Miyagi	MEXT
2		Yamagata	Yamagata	MEXT
3		Mito	Ibaraki	MEXT
4		Shinjuku	Tokyo	MEXT
5		Chigasaki	Kanagawa	MEXT
6		Ichihara	Chiba	MEXT
7		Saitama	Saitama	MEXT
8		Koufu	Yamanashi	MEXT
9		Shizuoka	Shizuoka	MEXT
10		Utsunomiya	Tochigi	MEXT
11		Maebashi	Gunma	MEXT
12		Fukushima	Fukushima	Fukushima Pref.
13		Iitate	Fukushima	Fukushima Pref.
14		Koriyama	Fukushima	Fukushima Pref.
15		Minami-soma	Fukushima	Fukushima Pref.
16		Iwakishi-taira	Fukushima	Fukushima Pref.
17		FNNP2**	Fukushima	TEPCO
18		Kita-ibaraki	Ibaraki	Ibaraki Pref.
19	Dust sampling	JAEA Tokai	Ibaraki	JAEA (JAERI, JNC)



*Fukushima Dai-ichi Nuclear Power Plant
**Fukushima Dai-ni Nuclear Power Plant

3月14～21日のJAEA東海での^{131}I大気中濃度の時系列比較

- 観測点の緯経度を含む格子(center)と、そこから16方位で18 km離れた格子の値をプロット

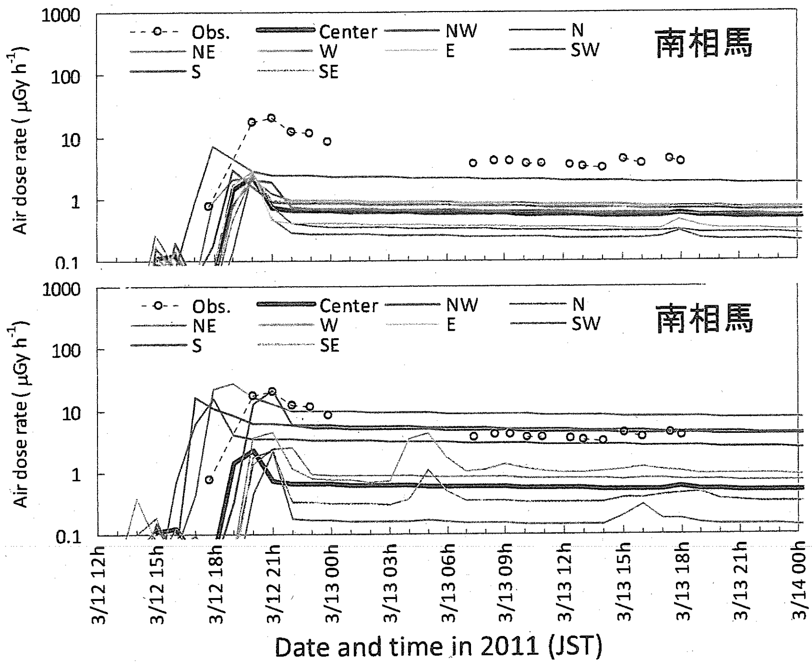


2011年3月12日午後のプルームによる線量上昇

- 観測点の緯経度を含む格子(center)と、そこから16方位で3および9 km離れた格子の計算値をプロット

3 km範囲

9 km範囲

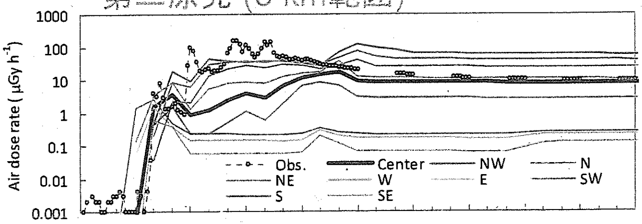


- 南相馬での線量率の立ち上がりのタイミングを良好に再現
- 乾性沈着核種による線量上昇を9 km範囲で再現

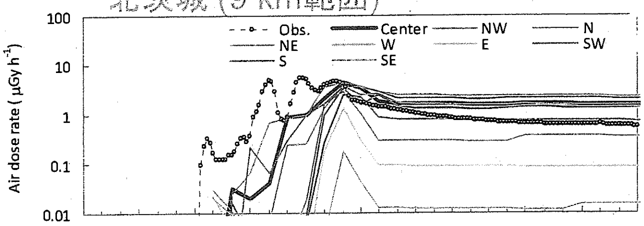
2011年3月15日明方に南下したプルームによる線量上昇

- 観測点の緯経度を含む格子(center)と、そこから16方位で3および9 km離れた格子の計算値をプロット

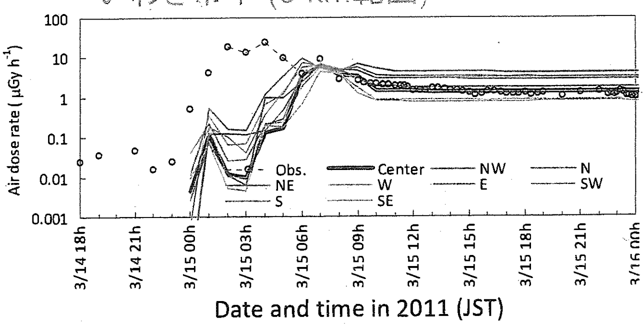
第二原発 (3 km範囲)



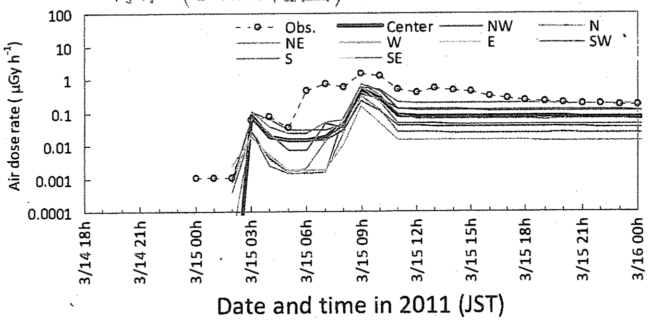
北茨城 (9 km範囲)



いわき市平 (9 km範囲)



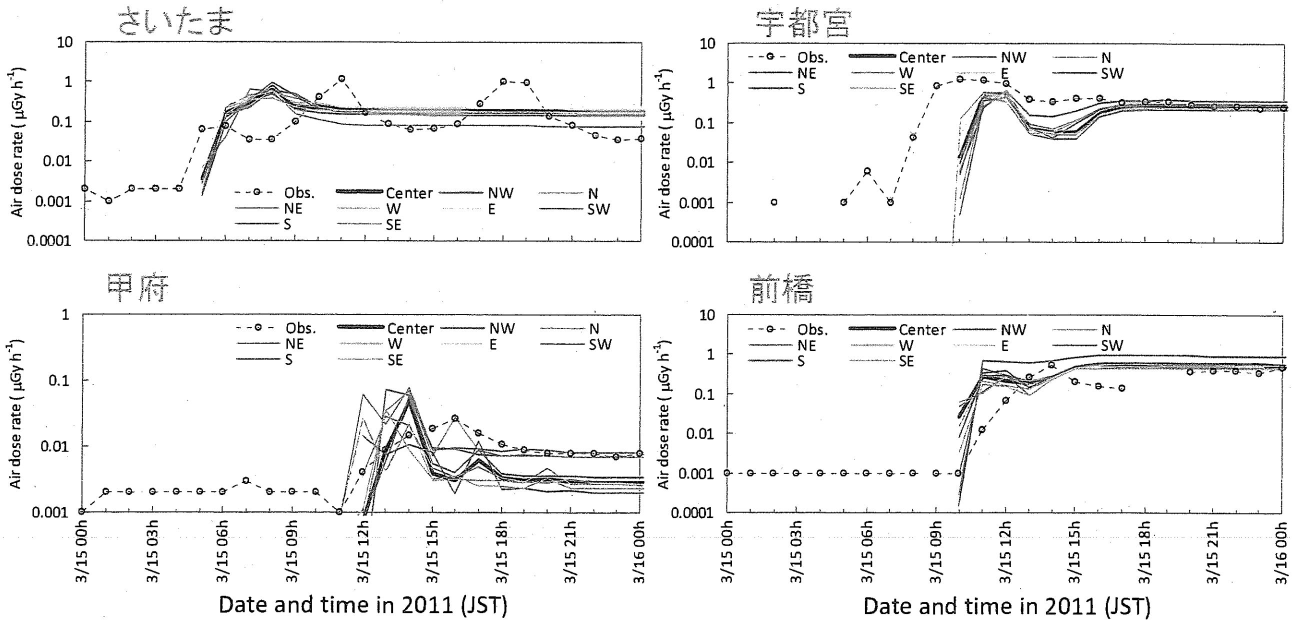
水戸(3 km範囲)



- 各地点の線量率の立ち上がりのタイミングを3時間以内のずれで再現
- 福島県・関東北部では、乾性沈着核種による線量上昇を9 km範囲で再現

2011年3月15日午後に通過したプルームによる線量上昇

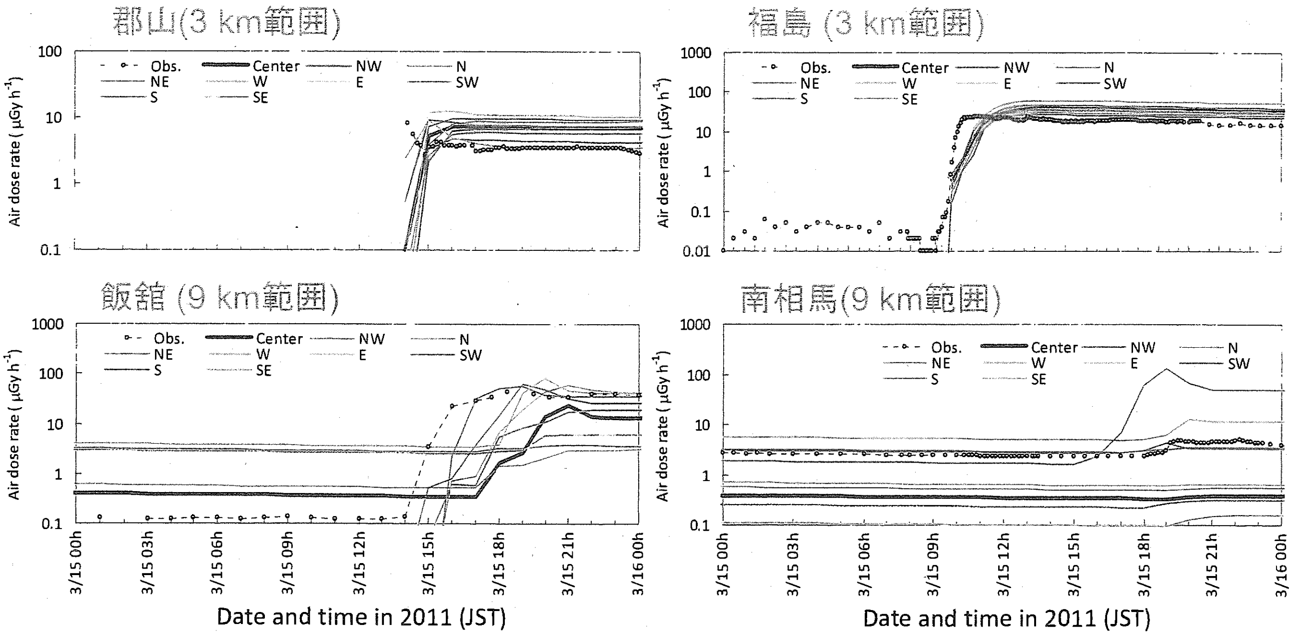
- 観測点の緯経度を含む格子(center)と、そこから16方位で3 km離れた格子の計算値をプロット



- 各地点の線量率の立ち上がりのタイミングを2時間以内のずれで再現
- 関東西部では、乾性・湿性沈着による線量上昇を3 km範囲で再現

2011年3月15日に福島県を通過したプルームによる線量上昇

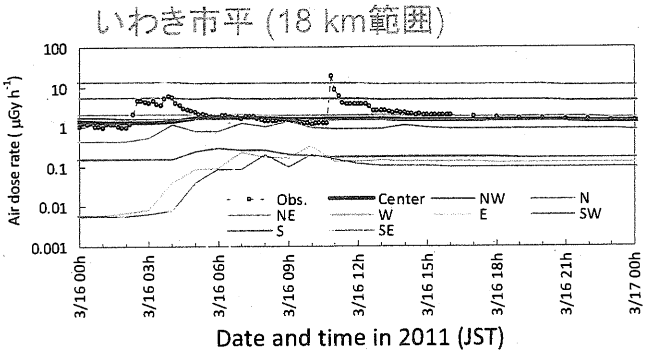
- 観測点の緯経度を含む格子(center)と、そこから16方位で3および9 km離れた格子の計算値をプロット



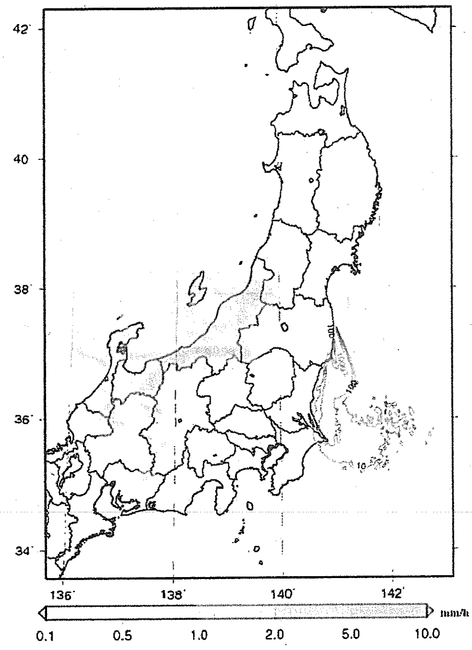
- 各地点の線量率の立ち上がりのタイミングを2時間以内のずれで再現
- 郡山・福島では、湿性沈着による線量上昇を3 km範囲で再現
- 飯舘・南相馬では、乾性・湿性沈着による線量上昇を9 km範囲で再現

2011年3月15日夜中に南下したプルームによる線量上昇

- 観測点の緯経度を含む格子(center)と、そこから16方位で<u>18 km離れた</u>格子の計算値をプロット



I-131地表濃度（コンター）＋降水量
9:00 JST on 16 March

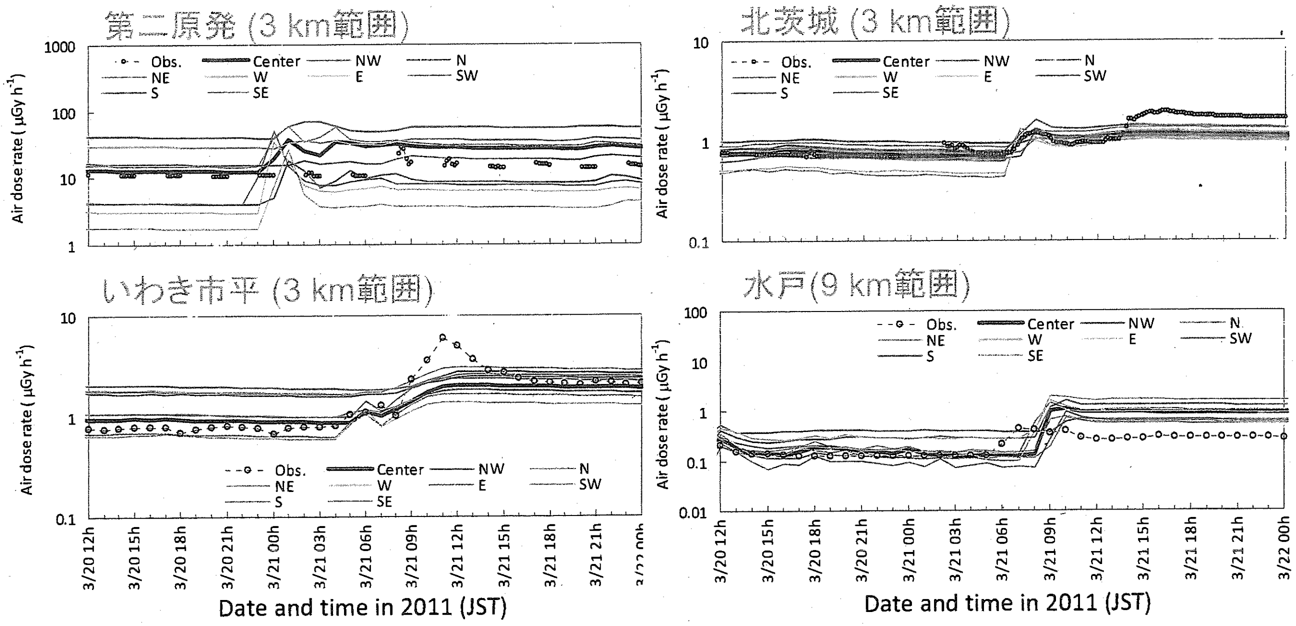


- プルームの軸が海側に大きくずれており、気象場計算の見直しが必要

⇒今後の課題

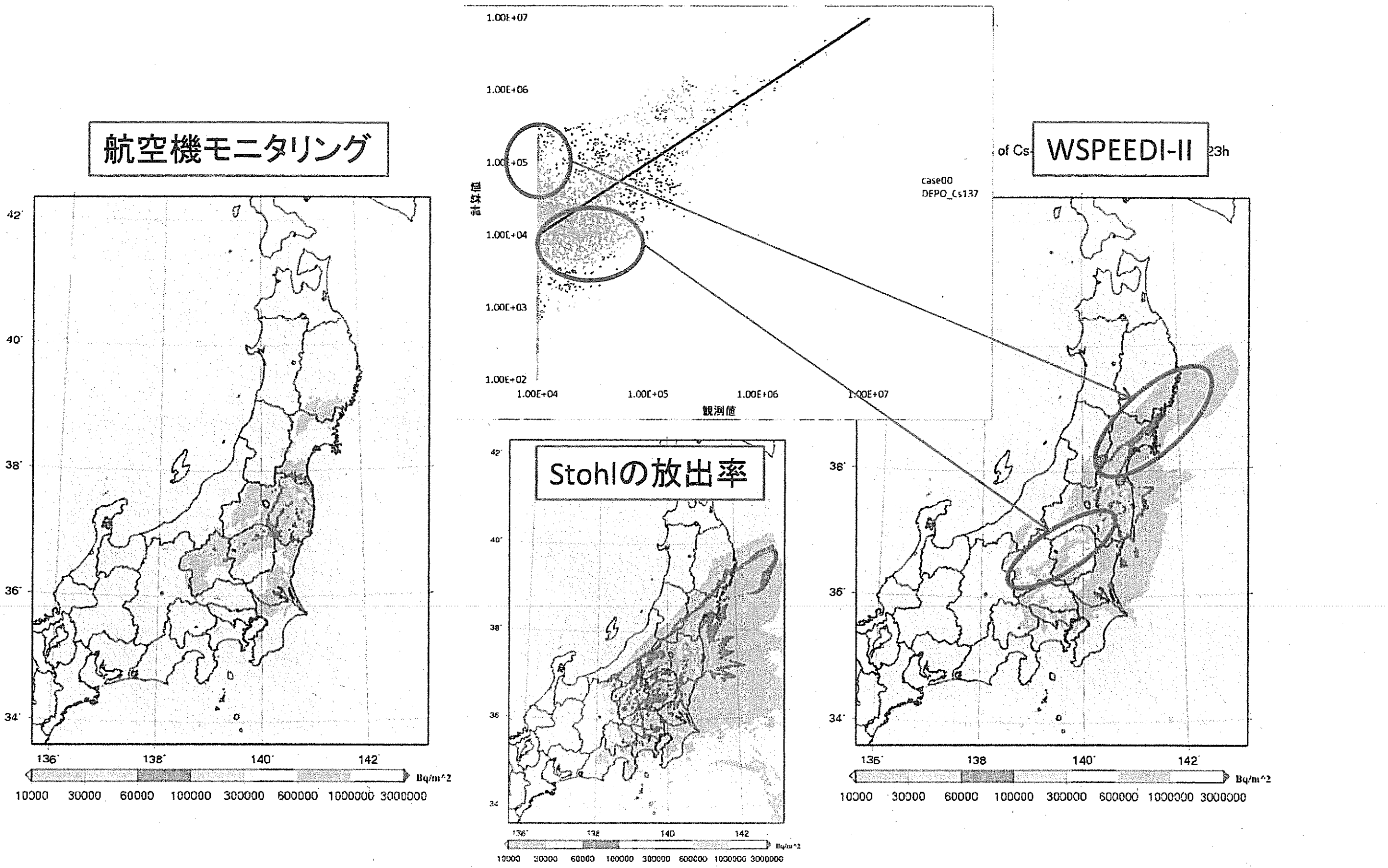
2011年3月21日に南下したプルームによる線量上昇

- 観測点の緯経度を含む格子(center)と、そこから16方位で<u>3および9 km離れた</u>格子の計算値をプロット

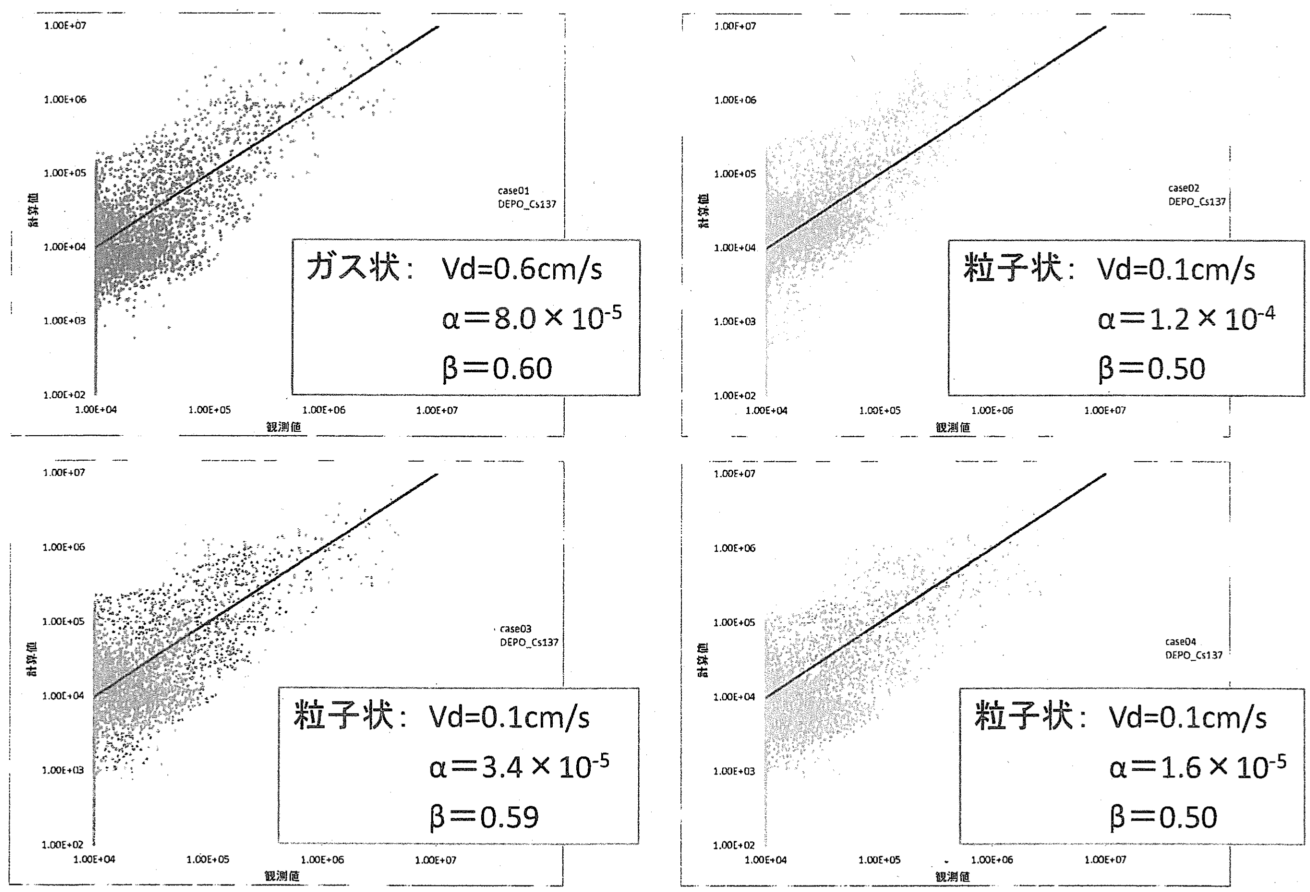


- 各地点の線量率の立ち上がりのタイミングを2時間以内のずれで再現
- 福島県・関東北部では、乾性沈着核種による線量上昇を 3～9 km範囲で再現

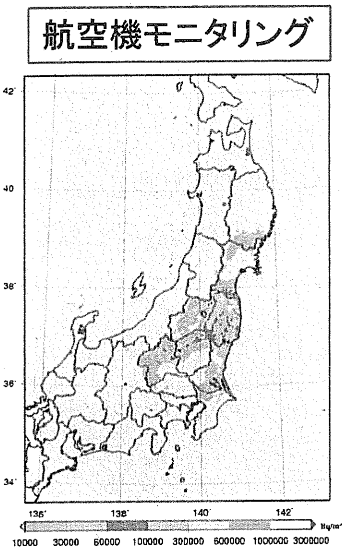
航空機モニタリングとの比較(オリジナルケース) 25/28

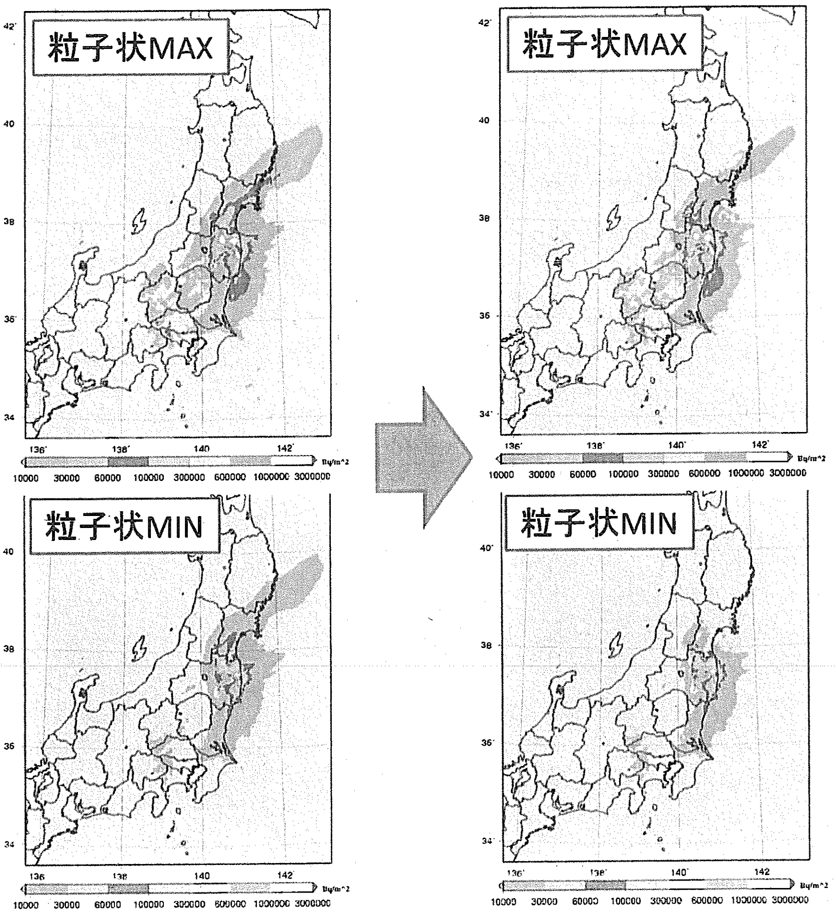


沈着過程の感度解析(ガス状・粒子状) 26/28



航空機モニタリングとの比較（氷相・液相の考慮）





湿性沈着過程において
氷相と液相の違いを考慮：
氷相の洗浄率Λ×0.1

まとめ

【放出源情報の検討】

- 対象核種：線量寄与率が大きい核種：I-131、I-133、Te-132、Cs-137
- 放出率時間変化：JAEAのI-131、Cs-137をベースに他核種は組成比から決定
  → 放出率のコントロールケース設定
- 放出源の不確実性：不確実性の影響が大きい期間をファクター3で変えて評価

【拡散解析】

- 測定との比較：通過時刻を3時間、通過位置を9km程度の範囲で再現
- 沈着パラメータの検討：ガス状ケース、粒子状3ケースの拡散計算DB作成
  → 各ケースの結合により、任意のガス・粒子割合の拡散解析が可能
- 沈着量の比較：湿性沈着過程の氷相と液相の洗浄率設定により再現性向上
  → さらなるモデル改良と放出源条件の精査が必要

1

資料③－3

Reconstruction of early internal dose in Fukushima NPS accident

Presentation material for expert committee on 8 Jan 2013

National Institute of Radiological Sciences

2

Results of early internal doses (thyroid)

Location	Committed equivalent dose to thyroid (mSv) Adults	Children
Fukushima Prefecture		
Iitate	30 (90%), < 10 (50%)	20 (90%), < 10 (50%)
Kawamata	10 (90%), < 10 (50%)	10 (90%), < 10 (50%)
Iwaki city	…	20 (90%), < 10 (50%)
Namie	20 (90%), < 10 (50%)	30 (90%), < 10 (50%)
Minami-soma	…	…
Futaba, Okuma, Tomioka Naraha	20 (90%), 10 (50%)	30 (90%), < 10 (50%)
Hirono	20 (90%), < 10 (50%)	30 (90%), 20 (50%)
Kawauchi	< 10 (90%)	< 10 (90%)
Rest of Fukushima Pref.	…	…
Neighboring Prefectures	…	…

Red: from thyroid measurements, Blue: from WB measurements, Black: from simulations and other methods

N.B.)Doses in the table are given for residents of each municipality at the time of accident.

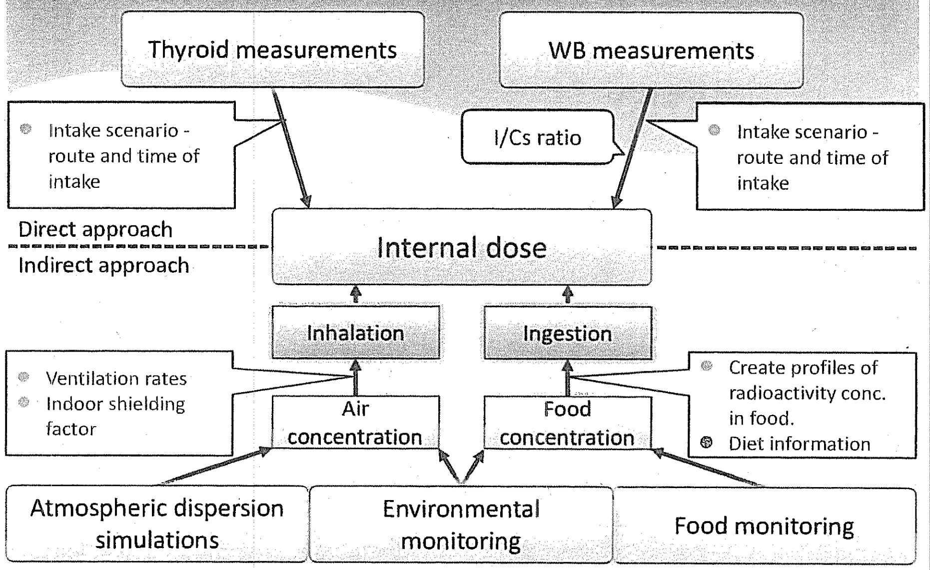
3

Contents

- Methods for reconstruction of early internal dose in the TEPCO Fukushima NPS accident
- Results of each method
  - Thyroid measurements
  - WB measurements
  - Atmospheric dispersion simulations
  - Ingestion
- Discussion

4

Methods for reconstruction of early internal dose



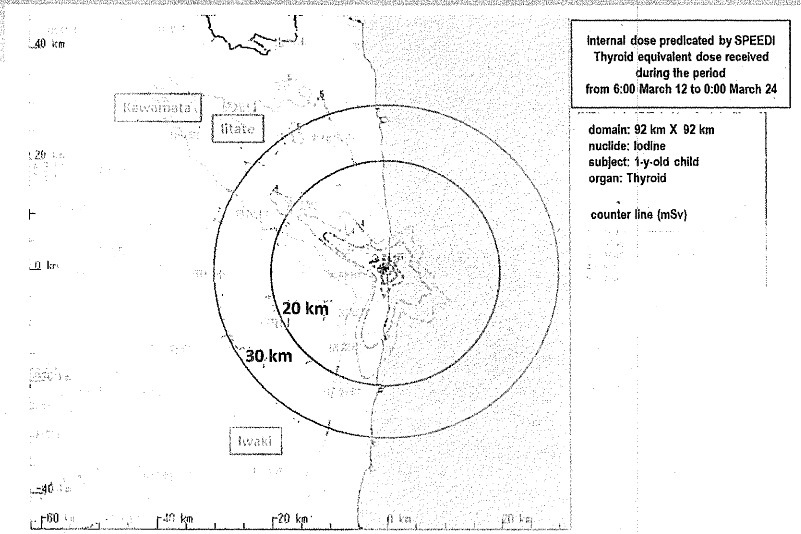
From thyroid measurements

Background

- Japanese government instructed residents living within 20 km-radius of the Fukushima Daiichi Nuclear Power Station (FDNPS) to evacuate outside on March 12 and those within 30 km-radius to stay indoors on March 15.
- On March 23, the Nuclear Safety Commission (NSC) of Japan performed preliminary calculations of thyroid equivalent doses for children using the System for Prediction of Environmental Emergency Dose Information (SPEEDI) along with a few environmental monitoring data. As a result, it was expected that areas where thyroid doses were relatively high existed beyond the evacuation zone (within 20 km radius).
- NSC ordered the local emergency headquarter to implement a screening survey on thyroid exposure for children in the above areas (Kawamata, Iitate, Iwaki).
- NIRS was in charge of establishing a protocol for the screening survey and University staff members performed measurements.
- The number of subjects in this survey is 1,080, which is the largest dataset of human thyroid measurements obtained in the FDNPS accident.

Additional info: Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety - The accident at TEPCO's Fukushima Nuclear Power Stations -, Chapter VI.
http://www.kantei.go.jp/foreign/kan/topics/201106/pdf/chapter_vi.pdf

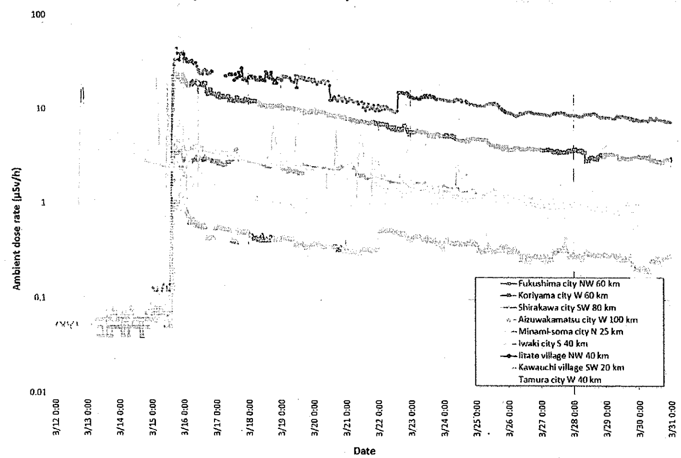
SPEEDI's Prediction



Nuclear Regulation Authority of Japan
http://www.nsr.go.jp/archive/nsc/mext_speedi/0312-0324_in.pdf

A likely intake scenario ...

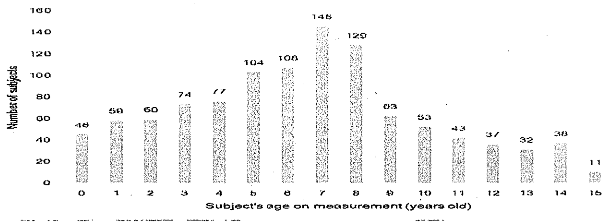
- Serious damages of infrastructure may largely reduce the intake via ingestion although this should be confirmed carefully.
- Ambient dose rates were firstly elevated on March 15 at many locations, suggesting the first exposure to the public.



Number of subjects for each location

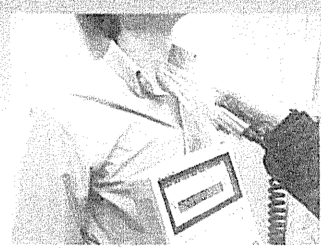
Date	Measurement location	Number of subjects	[illegible]
March 24	Heath care center (Kawamata)	18	(18)*1
	Yamakiya branch (Kawamata)	48	(48)*1
March 26-27	Health care center (Iwaki City)	137	134*2
March 28-30	Central community center (Kawamata)	631	631
March 29-30	Local government office (Iitate)	315	315
Total		1,149	1,080

*1 Excluded from evaluations due to high background levels of radiation.
*2 Excluded from evaluations due to age uncertainty.



How to perform the screening survey

- Devices: NaI(Tl) scintillation survey meters (types: TCS-161, TCS-171, TCS-172, Hitachi-Aloka Medical Ltd., Japan)
- Measurement setting
  - No sound mode
  - Time constant: 10 sec
  - Unit: μSv h^{-1}
  - Record the average value of three readings. Each reading value is obtained after 30 sec for the stabilization.



- Background measurement: at each measurement location for subtraction from Gross signals.

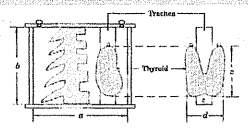
In fact, BG counts were individually obtained in some measurements. Exact information on this is unknown.

- Screening level: **0.2 μSv h^{-1}** corresponding to 100 mSv for 1 y-old children.
  - N.B.) This level was obtained based on the assumption of a continuous intake scenario from March 12 to March 23 and measurements on March 24.

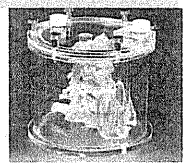
The intake scenario is the biggest uncertainty factor. The continuous intake scenario seems to be reasonable, but <u>is not conservative</u>.

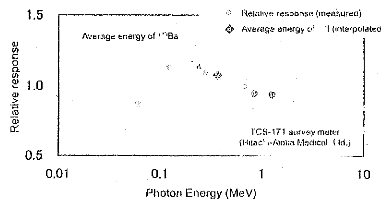
How to perform the screening survey –Cont'd

- Calibration:
  - Phantom (Kyoto Kagaku Co. Ltd.,) Ref. K. Nishizawa and H. Maekoshi, Health Phys. (1990).
  - The thyroid-shaped bag in the phantom was filled with ^{133}Ba standard solution, and calibration coefficients were then obtained.
  - The response function is relatively flat with photon energy. (^{133}Ba=^{131}I)
  - To simulate thyroids for small children, different volumes of the solution corresponding to the thyroid weight of each age group (1y, 6y and 15y) were loaded in the above bag without using other phantoms imitating children.



a:100 mm, b:100 mm, c: 55 mm, d:45 mm, e:20 mm





Predicted thyroid doses for different subject groups at the screening level of 0.2 μSv h^{-1}

Age group	[illegible]	[illegible]	[illegible]
1-y-old (1 y to 2 y)	2.5	4,400	108
5-y-old (2 y to 7 y)	6.1	4,690	64
15-y-old (12 y to 17 y)	20.5	6,030	16

Update calibration coefficients

- Calibration coefficients for small children are probably inappropriate.
- The difference in the size of neck and the thickness of soft tissue over the thyroids between ages should be taken into account.

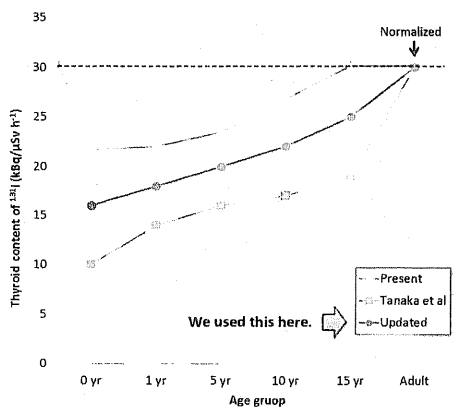
Table 3
Relative efficiency of detection and detection limit for ^{131}I in the thyroid gland as determined for phantoms using a scintillation survey meter

Phantom No.	Age, y	Relative efficiency of detection μR per h per nCi ^{131}I	Detection limit, nCi
I	0	0.47	3.9
II	1 2	0.15	3.9
III	3- 4	0.30	9.1
IV	11 16	0.26	9.2
V	25-50	26.4 kBq /μSv h^{-1}→ 0.16	19

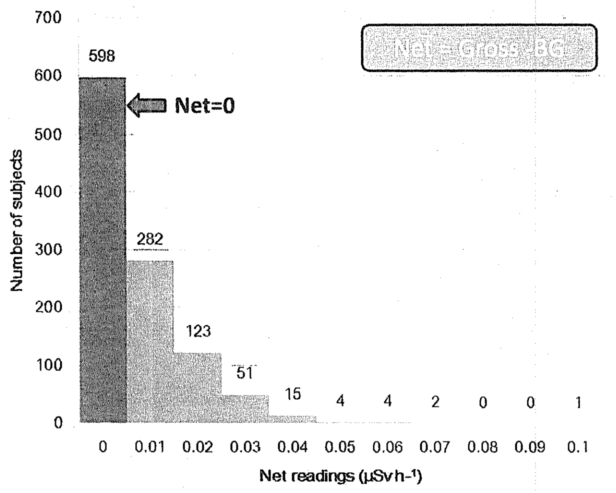
G. Tanaka and H. Kawamura, J. Radiat. Res. (1978)

Calibration coefficients for adult's thyroid

30.15	Present
32 ± 2	JAERI-Review 95-020 (TCS-161)
26.4	Tanaka and Kawamura



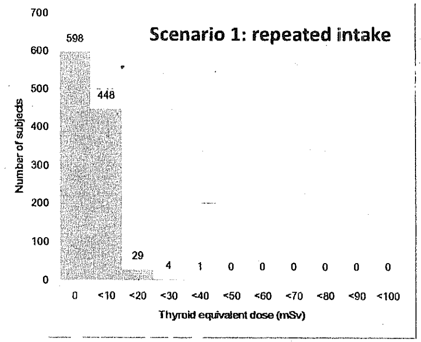
Readings from survey meters

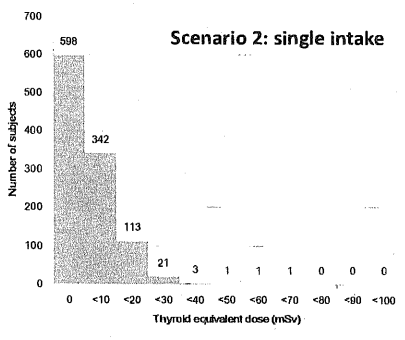


Nuclear Regulation Authority of Japan
http://www.nsr.go.jp/archive/nsc/anzen/shidai/genan2011/genan067/siryo1.pdf
(in Japanese)

Results of thyroid dose calculations

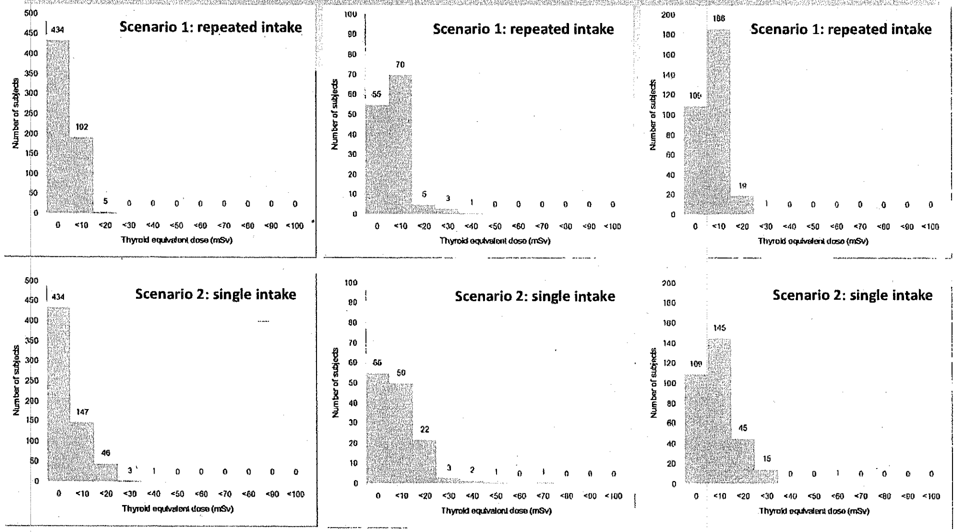
- **Assumption**
  - Route of intake: inhalation
  - Chemical form: elemental iodine (vapor)
- **Intake mode**
  - A repeated intake from March 12 to the day before measurements
  - A single intake on March 15





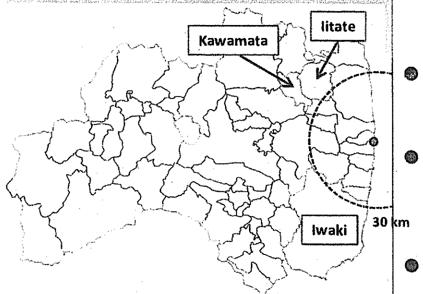
99.9% (Scenario 1) and 99.7% (Scenario 2) are below 30 mSv

Results of thyroid dose calculations –Cont'd



Kawamata | Iwaki | Iitate

What can we say ?



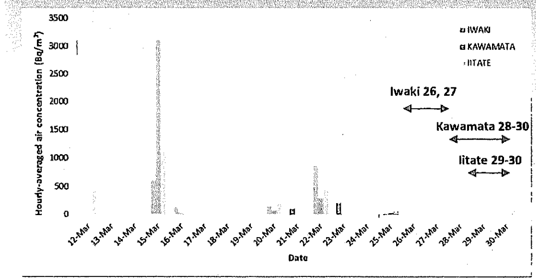
- Thyroid doses were calculated as less than 30 mSv for almost all of the subjects regardless of different intake scenarios.
- There is a very low possibility that thyroid doses exceeds 100 mSv for children in Kawamata and Iitate; the monitoring ratio is small for Iwaki.
- Assuming inhalation in the same exposure condition as children, adults' thyroid doses are estimated to be about a half of those of children. (i.e., considering ventilation rate x dose coff.)
- A single intake scenario would give some overestimations of internal doses (especially, Iwaki).

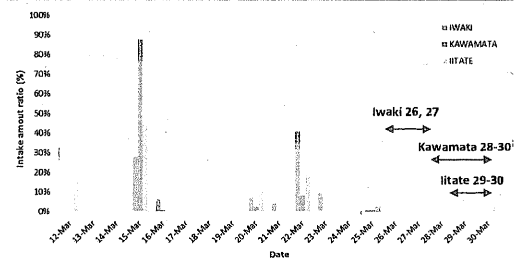
Monitoring ratio for each area

	Kawamata	Iwaki	Iitate
Subjects	631	134	315
Population (under ≤ 15)*	1917	50482	865
Monitoring ratio	**33%**	**0.3%**	**36%**

* National population census in fiscal year of 2010

Use of atmospheric dispersion simulations for internal dose estimations





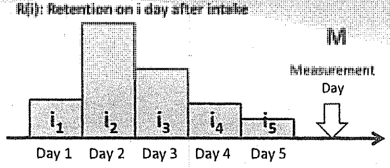
Data obtained from WSPEEDI-II

- From thyroid measurements
  30 mSv of thyroid dose
  ⇨ 10000 Bq intake (1 yr) ~
  50000 Bq intake (10 yr)
- From simulations
  1 day intake = 1000 Bq/h •24 h/day
  Overestimations for Kawamata ?
  (plume was transported at night on March 15)

- Intake scenario based on simulations
  ⇨ Non-uniform repeated intake
  Two times of intake with different magnitudes in Iwaki

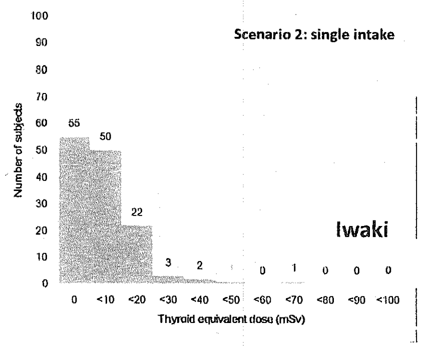
Refine internal dose calculations including intake scenario based on simulations

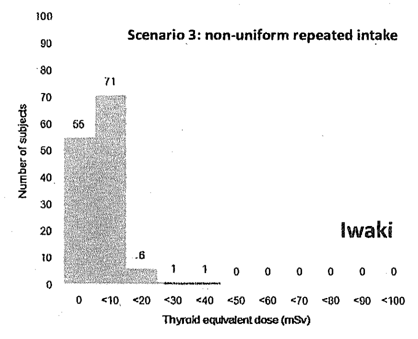
M: Thyroid content
I_i: Intake on i day
R(i): Retention on i day after intake



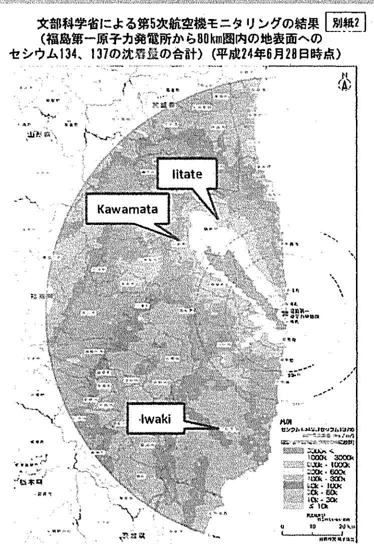
$M=i_1*R(5)+i_2*R(4)+i_3*R(3)+i_4*R(2)+i_5*R(1)$
$=I(f_1*R(5)+f_2*R(4)+f_3*R(3)+f_4*R(2)+f_5*R(1))^{*}I$

$(I=i_1+i_2+i_3+i_4+i_5,\ f_i=i_i/I)$

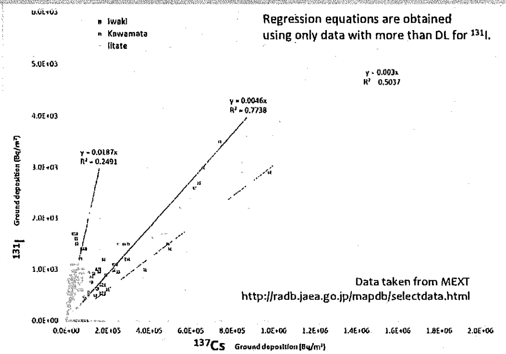




Ground surface deposition



http://radioactivity.mext.go.jp/ja/contents/7000/6289/24/203_0928.pdf



Ground surface deposition of ^{131}I and ^{137}Cs
(Corrected at June 14, 2011)

- The deposition ratio ($^{131}I/^{137}Cs$) is higher in Iwaki than in the other areas. This is considered to be due to the difference in deposition processes: wet deposition is dominant in Iitate.
- Although the deposition ratio is not directly linked with a ratio in air concentration, there is no evidence that iodine in air is higher in Iwaki than the other two areas.

Another thyroid measurements dataset

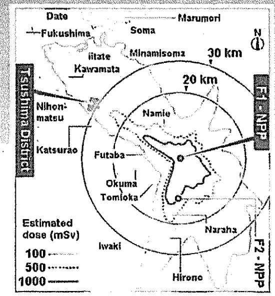
Tokonami et. al. (2012)

SCIENTIFIC REPORTS

Thyroid doses for evacuees from the Fukushima nuclear accident

SUBJECT AREAS: NUCLEAR PHYSICS ENERGY

Shinji Tokonami, Masahiro Hosoda, Suminori Akiba, Atsuyuki Sorimachi, Ikuo Kashiwakura & Mikhail Balonov



Summary

- Measurement location: Tsushima district in Namie town.
- Measurement period: April 12-16, 2011.
- Subjects: **45** evacuees from costal areas and **17** residents in Tsushima district.
  Positive detection in the two groups: 39 (87%) for evacuees
  7 (41%) for Tsushima residents
- Maximum thyroid doses: **23 mSv** for children and **33 mSv** for adults
- Intake scenario for dose estimations: a single intake on March 15.

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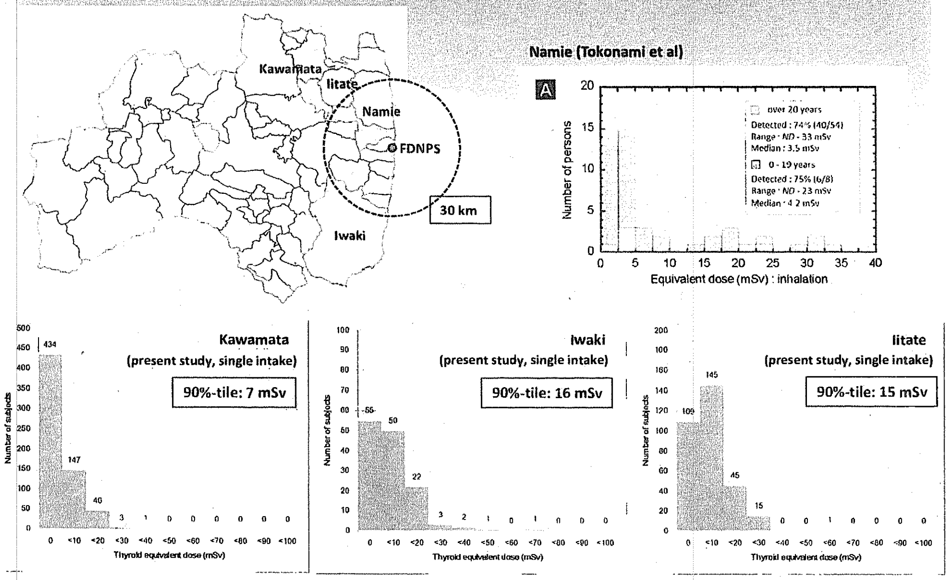
Thyroid dose distribution map from thyroid measurements



22

Results of early internal doses (thyroid)

Location	Committed equivalent dose to thyroid (mSv) Adults	Children
Fukushima Prefecture		
Iitate		20 (90%), < 10 (50%)
Kawamata		10 (90%), < 10 (50%)
Iwaki city		20 (90%), < 10 (50%)
Namie		
Minami-soma		
Futaba, Okuma, Tomioka Naraha		
Hirono		
Kawauchi		
Rest of Fukushima Pref.		
Neighboring Prefectures		

Red: from thyroid measurements, Blue: from WB measurements, Black: from simulations and other methods

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From WB measurements

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Background

- Whole body (WB) measurements for Fukushima residents have been carried out since last June 27, 2011.
- ^{131}I could be not be detected anymore. Only ^{134}Cs and ^{137}Cs have been detected.
- Two datasets of the WB measurements are available in this study although raw data (i.e., WB contents of Cs and exact days of measurement) are not fully available.
- The reconstruction of early internal doses is attempted from the WB measurements using a reasonable intake ratio of $^{131}I/^{137}Cs$.

WB measurements by NIRS

- Measurement period: from June 27 to July 16 in 2011.
- Subjects: 122 residents* in Namie-town, Iitate-village, Kawamata-town (Yamakiya district) (*only 109 data are published.)

http://www.pref.fukushima.jp/imu/kenkoukanri/230724shiryou.pdf

WB measurements by JAEA

- Measurement period: July 11, 2011 – the end of January, 2012 (still ongoing)
- Subjects: 9,927 Fukushima residents (mostly, small children)

T. Momose, NIRS Proceedings

Intake scenario for dose estimations: a single intake on March 12, 2011.

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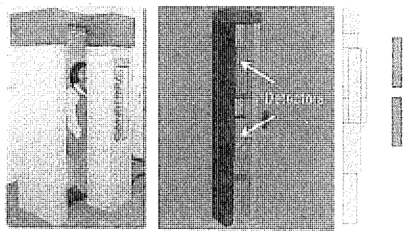
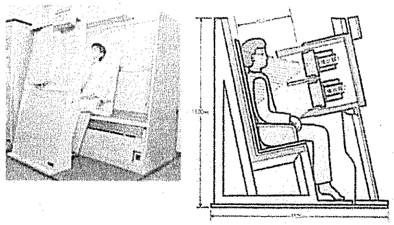
WB measurements by JAEA

Lab.1 | **Inspection capability: 100 subjects/day (4h)** | **Lab.2**





- **Canberra FASTSCAN (2 systems)**
- **Detector: 16"*5"*3" NaI(Tl) 2 Units**
- **Shield: low BG steel sheets 10 cm**
- **Detection limit: 200 Bq (^{137}Cs, 2 min)***
- **Energy range: 0.3-1.8 MeV**
- **Use for purpose: Screening**

* Normal BG conditions

- **Fuji electric. WBC (1 system)**
- **Detector: 8"ϕ*4" NaI(Tl) 1 Unit**
- **Shield: Pb 5 cm**
- **Detection limit: 220 Bq (^{137}Cs, 2 min)***
- **Energy range: 0.15-2 MeV**
- **Use for purpose: Screening**

Detection limits for Cs increased to 300 Bq after the TEPCO Fukushima NPS accident.

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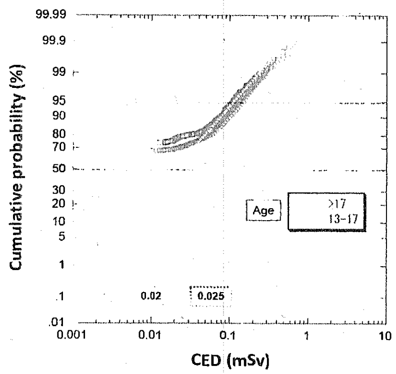
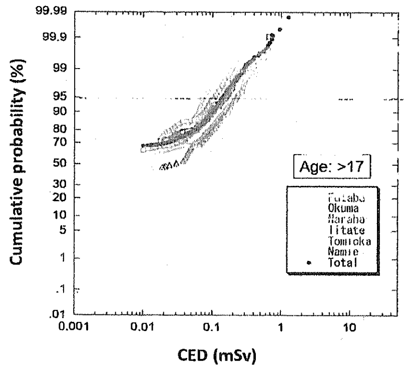
Internal dose estimations from WB measurements

- JAEA performed internal dose estimations of subjects based on the assumption of a single intake scenario on March 12, 2011.
- This intake scenario would give some overestimations of internal doses since the possibility of late intake increases with time after the accident.
- Only dose estimate results are currently available for JAEA's WB measurements.





Ref.) T. Momose et al, NIRS proceedings

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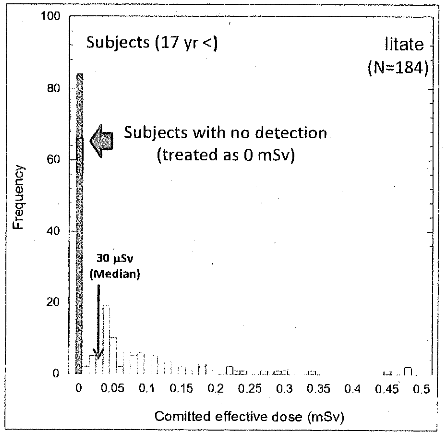
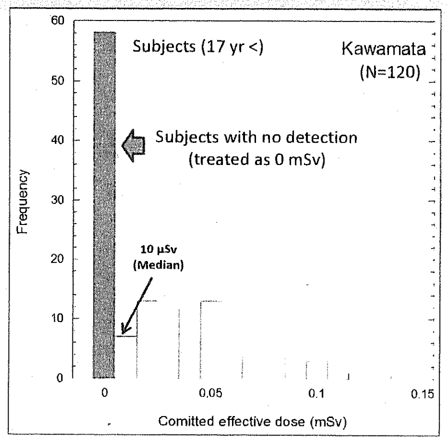
Dose distributions from WB measurements (1)

- No detection for a half of the subjects in Iitate and Kawamata.
- A intake amount ratio ($^{131}I/^{137}Cs$)were evaluated from the median value of individual doses.





(**Zero** mSv is assigned to internal doses in case of no detection)

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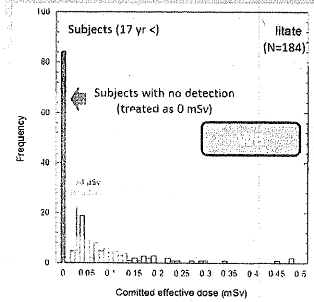
Comparison between thyroid screening survey for children and WB measurements for adults (Iitate)



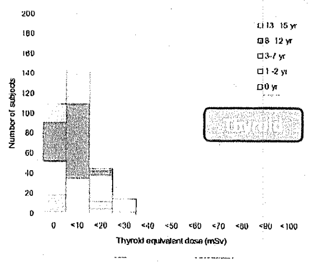
Estimate intake amount (Cs)

Median: 30 μSv in CED from ^{134}Cs & ^{137}Cs (**adults**)

⇨ **~ 3000 Bq for each Cs**

Assumption { A single intake via inhalation; Default physicochemical form (Type F, 1 μm) }

Intake ratio ($^{131}I/^{137}Cs$) = 5~10



Estimate intake amount (I)

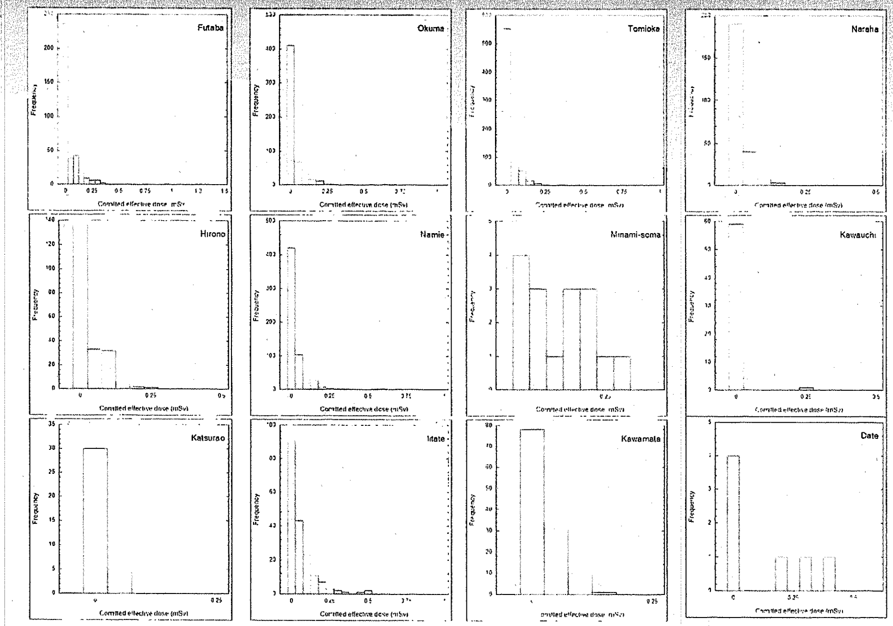
Median: 10 mSv in thyroid dose from ^{131}I (**children**)

⇨ 5000 Bq (3~7y) ~ 10000 Bq (8~12y) from ^{131}I

Assumption { A single intake via inhalation; Elemental iodine }

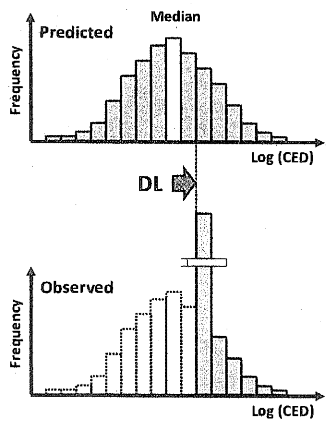
⇨ **15000 Bq ~ 25000 from ^{131}I (adults)**
(considering the difference in ventilation rates for children and adults)

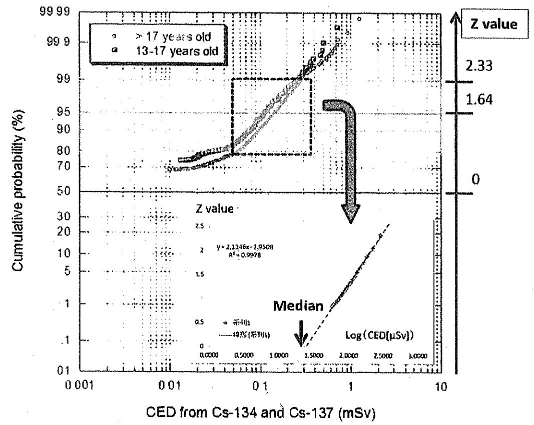
Dose distributions from WB measurements (2)



Prediction of median CED values

- A median CED value exists in the lowest dose band (corresponding to DL of WB measurements) for most of municipalities.
- Median CED values are calculated assuming a log-normal distribution of CEDs (Momose et al, NIRS Proceedings).





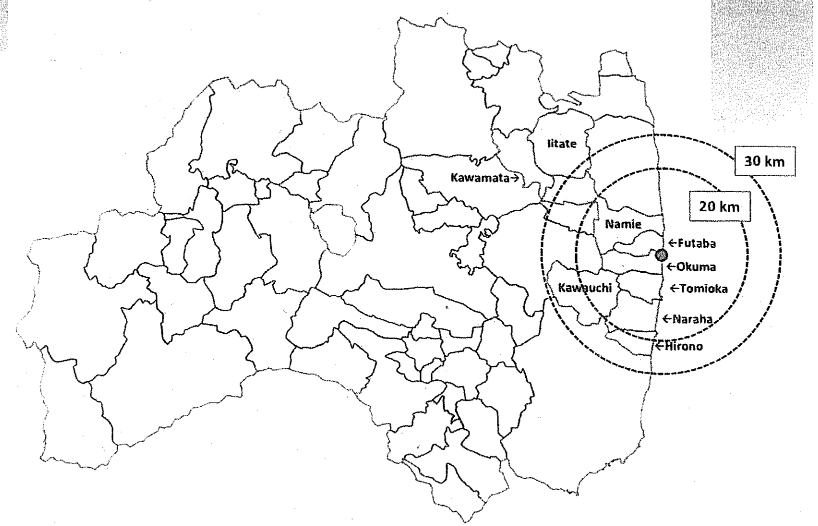
Median CED values for municipalities

All subjects for each municipality are 17 yr-old <. (Unit: mSv)

Municipality	N	90%-tile CED	50%-tile CED	Corr. (R^2)
Futaba	365	0.15	0.04	0.9901
Okuma	561	0.10	0.02	0.9901
Naraha	241	0.06	0.01	0.8789
Iitate	184	0.17	0.03*1	N.A.
Tomioka	696	0.08	0.01	0.8789
Namie	614	0.10	0.02	0.9876
Hirono	210	0.10	0.05	0.9919
Kawauchi	64	< 0.01	< 0.01	N.A.
Kawamata	120	0.07	0.01*1	N.A.
All (17 yr<)*2	3128	0.10	0.02	0.9978
All (13-17 yr)*2	1565	0.08	0.02	0.9918

*1 The 50-tile values are directly obtained.
*2 Including three municipalizes (Date, Minami-soma, Katsurao) other than those listed in Table.

Locations of municipalities with WB measurements available



Estimation of thyroid doses from WB measurements (Approach)

1 mSv in CED from ^{134}Cs & ^{137}Cs for adults

↓

Intake via inhalation: 9E+04 Bq for each Cs

↓ ← $^{131}I/^{137}Cs$ ratio= 1

Intake via inhalation: 9E+04 Bq for ^{131}I

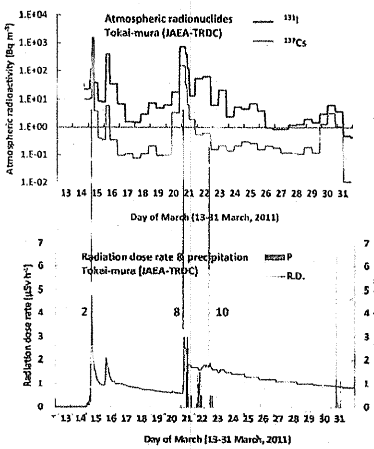
1 yr-children	10 yr-children	Adults
Ventilation rate: 5.16 m^3/day	Ventilation rate: 15.3 m^3/day	Ventilation rate: 15.3 m^3/day
^{131}I Intake: 2E+04 Bq	^{131}I Intake: 6E+04 Bq	^{131}I Intake: 9E+04 Bq

- Dose coefficients of iodine (vapor: particle = 0.6: 0.4) are used.
- Contribution from other nuclides was assumed to be 10%.

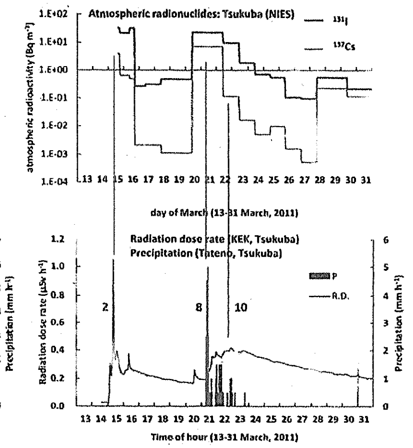
Thyroid dose: 60 mSv	Thyroid dose: 50 mSv	Thyroid dose: 30 mSv

Air concentration ratio of $^{131}I/^{137}Cs$

Ref.) H. Tsuruta et al, NIRS proceedings



(1) Tokai-mura (JAEA-TRDC)



(2) Tsukuba (NIES)

- The ratio ($^{131}I/^{137}Cs$) was around 10 on March 15 and March 20-21.
- Integrated air concentration ratio ($^{131}I/^{137}Cs$) at JAEA Tokai-sites was also nearly 10.

Thyroid doses from WB measurements (1)

$^{131}I/^{137}Cs$= 10 (Unit: mSv)

Municipality	90%-ile 1 yr	90%-ile 10 yr	90%-ile Adults	50%-ile 1 yr	50%-ile 10 yr	50%-ile Adults
Futaba	90	80	50	20	20	10
Okuma	60	50	30	10	10	< 10
Naraha	40	30	20	< 10	< 10	< 10
Iitate	100	90	50	20	20	< 10
Tomioka	50	40	20	< 10	< 10	< 10
Namie	60	50	30	10	10	< 10
Hirono	60	50	30	30	30	20
Kawauchi	< 10	< 10	< 10	< 10	< 10	< 10
Kawamata	40	40	20	< 10	< 10	< 10
Average*	60	50	30	10	10	< 10

* Obtained from WB measurements of all municipalities analyzed.

Thyroid doses from WB measurements (2)

$^{131}I/^{137}Cs$= 5 (Unit: mSv)

Municipality	90%-ile 1 yr	90%-ile 10 yr	90%-ile Adults	50%-ile 1 yr	50%-ile 10 yr	50%-ile Adults
Futaba	50	40	20	10	10	< 10
Okuma	30	30	20	< 10	< 10	< 10
Naraha	20	20	10	< 10	< 10	< 10
Iitate	50	40	30	< 10	< 10	< 10
Tomioka	20	20	10	< 10	< 10	< 10
Namie	30	30	20	< 10	< 10	< 10
Hirono	30	30	20	20	10	< 10
Kawauchi	< 10	< 10	< 10	< 10	< 10	< 10
Kawamata	20	20	10	< 10	< 10	< 10
Average*	30	25	15	< 10	< 10	< 10

* Obtained from WB measurements of all municipalities analyzed.

A better agreement with thyroid measurements...

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Results of early internal doses (thyroid)

Location	Committed equivalent dose to thyroid (mSv) Adults	Children
Fukushima Prefecture		
Iitate	30 (90%), < 10 (50%)	20 (90%), < 10 (50%)
Kawamata	10 (90%), < 10 (50%)	10 (90%), < 10 (50%)
Iwaki city		20 (90%), < 10 (50%)
Namie	20 (90%), < 10 (50%)	30 (90%), < 10 (50%)
Minami-soma		
Futaba, Okuma, Tomioka Naraha	20 (90%), 10 (50%)	30 (90%), < 10 (50%)
Hirono	20 (90%), < 10 (50%)	30 (90%), 20 (50%)
Kawauchi	< 10 (90%)	< 10 (90%)
Rest of Fukushima Pref.		
Neighboring Prefectures		

Red: from thyroid measurements, Blue: from WB measurements, Black: from simulations and other methods

N.B.)Doses in the table are given for residents of each municipality at the time of accident.

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From atmospheric dispersion simulations

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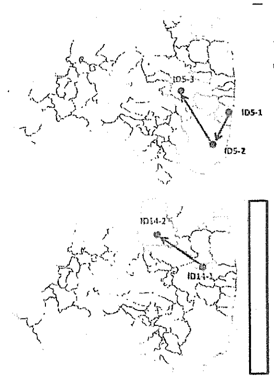
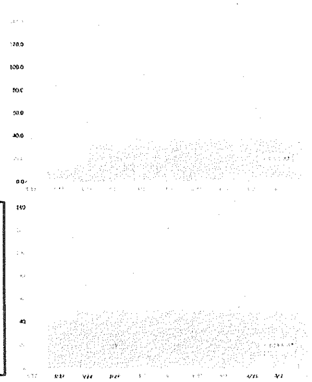
Atmospheric dispersion simulations of radionuclides for internal dose estimates

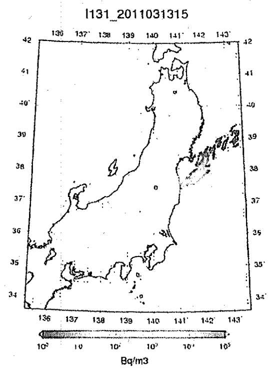
- Applied to persons without any individual monitoring data.
- For better understanding on intake situations during evacuation.
- For extensive dose estimations of people in neighboring Prefectures



Examples of evacuation patterns



Time trend of internal doses



WSPEEDI
Movement of plume on March 15-17

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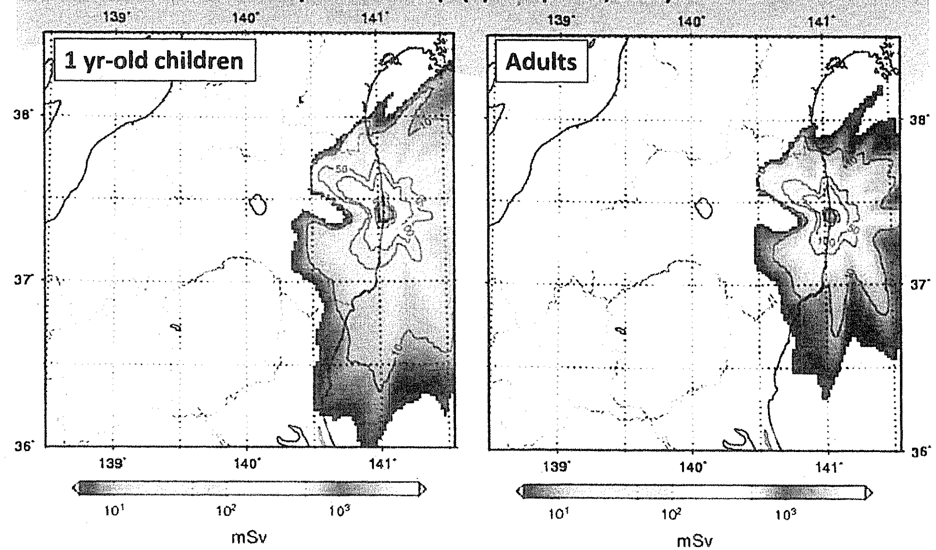
Thyroid dose maps by WSPEEDI

Thyroid dose map (up to April 30, 2011)



Internal dose calculations from WSPEEDI

- **WSPEEDI**: Worldwide version of the SPEEDI system
  - **SPEEDI**: System for Prediction of the Environmental Emergency Dose Information
  - Both the systems were developed by JAEA. The SPEEDI system has been operated by MEXT.
- Air concentration maps (^{131}I and ^{137}Cs) calculated by the latest version of WSPEEDI were used in the present study. **Ref.) G. Katara et al., (2012).**
- Internal doses were calculated by the following equation.

$$D = e_i \cdot B_i \cdot \int_{T_1}^{T_2} C(t) \cdot dt$$

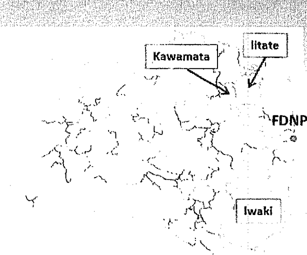
e_i: Dose coefficient for age group i (Sv/Bq) Ref. ICRP CD-ROM1

B_i: Ventilation rate for age group i (m^3/h). Ref. ICRP Publ. 71

$C(t)$: Air concentration (Bq/m^3) (every hour and every 3 km-mesh)

- Air concentration was obtained from the nearest grid to a local government office at each municipality and neighboring eight grids (nine grid data in total).

Comparison of dose estimates between human measurements and simulations (1)



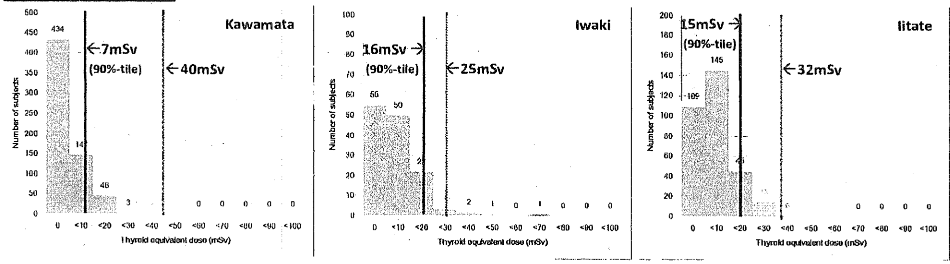
- Thyroid measurements for children living in three municipalities.
- Perform comparison of estimated thyroid doses between human measurements and WSPEEDI's simulations.
  - Assumption: stay outdoors all the time (no protection factors are considered).
  - Dose coefficients for iodine-131: 60% vapor, 40% Type F aerosols

Thyroid doses estimated by WPEEDI (5 yr-old children)

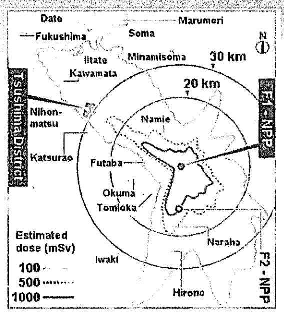
Kawamata	Iwaki	Iitate
40 mSv (1.3)*	25 mSv (1.1)*	32 mSv (1.6)*
Mar.12-Mar. 30	Mar.12-Mar. 27	Mar.12-Mar. 30

* Numbers outside and inside brackets are GMs and GSDs among 9 point-calculations

Red figures: WSPEEDI
Blue figures: Observed



Comparison of dose estimates between human measurements and simulations (2)



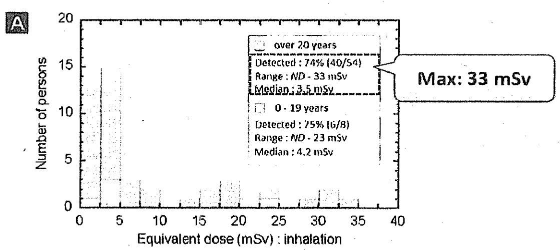
Tokonami et al., (2012).

- Thyroid measurements for adults in Tsusima district of Namie town.
- Perform comparison of estimated thyroid doses between human measurements and WSPEEDI's simulations.
  - Assumption: stay outdoors all the time (no protection factors are considered).
  - Dose coefficients for iodine-131: 100% vapor (same as Tokonami et al.)

Thyroid doses estimated by WPEEDI (Adults)

Tsushima district of Namie town	Center of Namie town
65 mSv (1.3)*.	Over 100 mSv
Mar.12-Mar. 31	Mar.12-Mar. 31

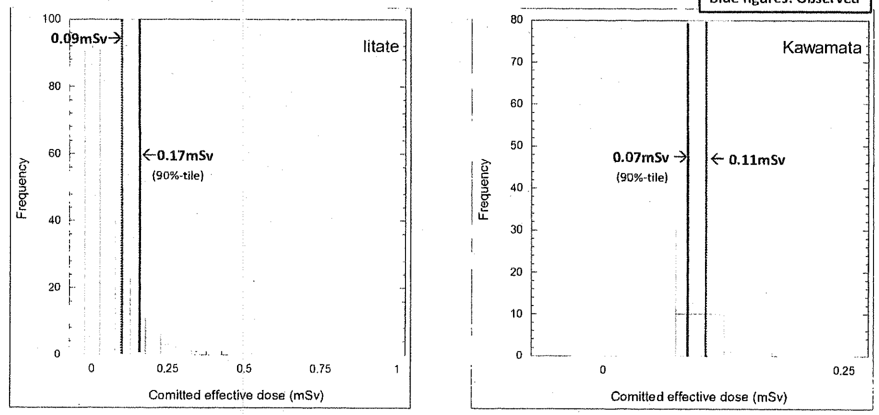
* Numbers outside and inside brackets are GMs and GSDs among 9 point-calculations



Comparison of dose estimates between human measurements and simulations (3)

- Perform comparison of estimated effective doses from ^{134}Cs and ^{137}Cs between human WB measurements and WSPEEDI's simulations.
  - Assumption: the same air concentration between ^{134}Cs and ^{137}Cs.
  - Dose coefficients: Type F, AMAD 1 μm (for adults)
  - Exposure period: by the end of April 30

Red figures: WSPEEDI
Blue figures: Observed



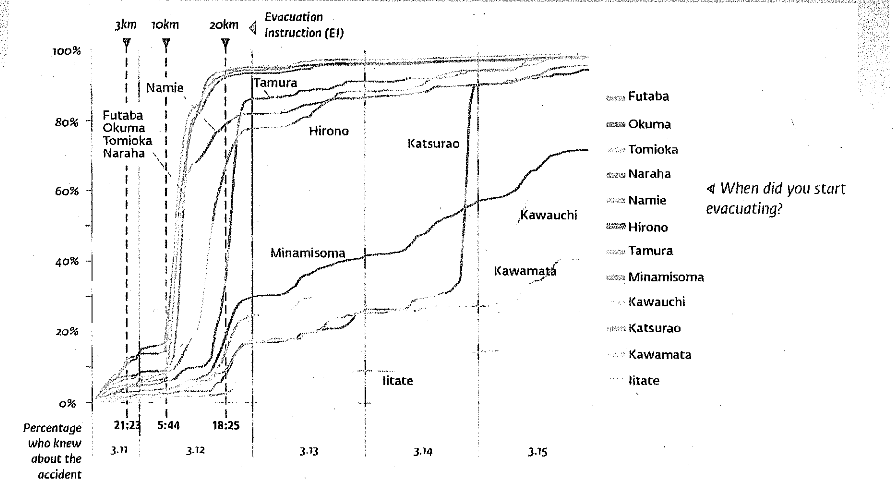
Comparison of dose estimates betwe… human measurements and simulations (4)

- Same calculations as the previous slide other than an exposure period.
- Most of residents in the municipalities listed were evacuated shortly after the accident.

Municipality	CEDs by WB measurements (mSv)		CEDs by WSPEEDI for different exposure periods (mSv) [illegible]				
	90%-tile	50%-tile	By Mar. 12 24:00	By Mar. 13 24:00	By Mar. 14 24:00	By Mar. 15 24:00	By Mar. 16 24:00
Futaba	0.15	0.04	0.04 (6.7)	0.04 (6.7)	0.04 (6.9)	0.41 (5.5)	0.41 (5.5)
Okuma	0.10	0.02	N.A.	N.A.	N.A.	0.80 (9.4)	0.84 (9.0)
Tomioka	0.08	0.01	N.A.	N.A.	0.02 (2.6)	0.23 (2.3)	0.23 (2.2)
Naraha	0.06	0.01	N.A.	N.A.	0.01 (2.5)	0.11 (2.7)	0.11 (2.6)
Hirono	0.10	0.05	N.A.	N.A.	N.A.	0.03 (2.5)	0.04 (2.4)
Namie	0.10	0.02	0.03 (2.8)	0.04 (2.7)	0.04 (2.7)	0.13 (6.4)	0.13 (6.4)
(Tsushima)	---	---	N.A.	N.A.	N.A.	0.20 (1.3)	0.21 (1.3)
Kawauchi	< 0.01	< 0.01	N.A.	N.A.	N.A.	0.01 (3.1)	0.01 (2.8)

* N.A. : Not calculated due to very small values

Time of evacuation

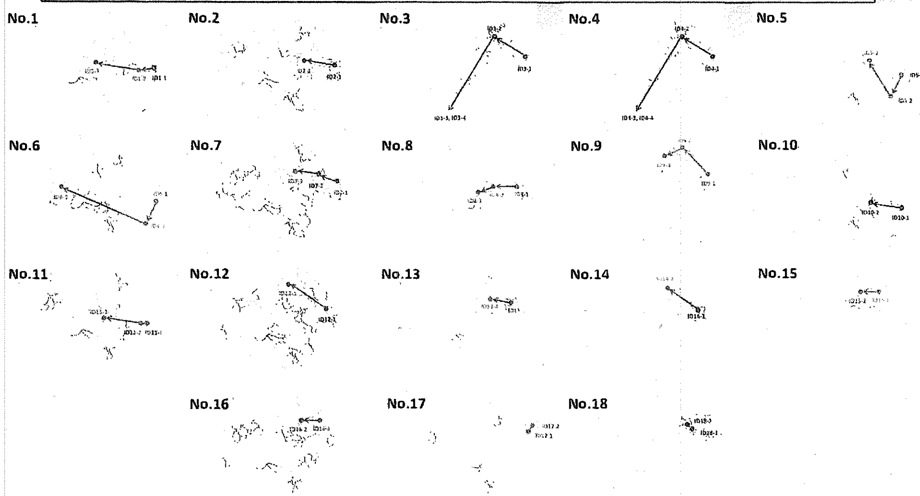


Ref.) The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission

http://warp.da.ndl.go.jp/info:ndljp/pid/3856371/naiic.go.jp/en/report/index.html

Prediction of internal doses for people with representative evacuation patterns

- 18 representative evacuation patterns were determined as model cases of evacuation from the restricted area (with in 20-km radius of FDNPS) or the deliberate evacuation area in external dose estimations of Fukushima residents.



Prediction of thyroid doses for people with representative evacuation patterns

Thyroid equivalent doses from ^{131}I for different age groups (mSv)

Case No.	1	2	3	4	5	6	7	8	9
1 yr	< 10	< 10	40	90	30	10	90	< 10	< 10
10 yr	< 10	< 10	40	70	30	< 10	80	< 10	< 10
Adults	< 10	< 10	20	40	20	< 10	50	< 10	< 10

Case No.	10	11	12	13	14	15	16	17	18
1 yr	10	< 10	< 10	100	40	30	30	80	70
10 yr	< 10	< 10	< 10	90	30	30	30	70	60
Adults	< 10	< 10	< 10	50	20	20	20	40	30

Note)

- No simulation factors were used (24 h outdoors).
- Dose coefficients for ^{131}I: 60% vapor, 40% Type F aerosols with AMAD of 1 μm
- A half air concentration value at the original location and destination was used during movements.
- A single grid value (the nearest grid) was used for each location.

Model Case No.13: people who stayed at Tsushima district until March 23 at 10:00 AM and then departed for Nihonmatsu city.

Prediction of effective doses for people with representative evacuation patterns

CEDs from ^{134}Cs and ^{137}Cs for different age groups (mSv)

Case No	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1 yr	< 0.01	< 0.01	0.03	0.06	0.03	0.01	0.06	< 0.01	0.01
10 yr	< 0.01	< 0.01	0.06	0.12	0.06	0.01	0.13	< 0.01	0.01
Adults	0.01	< 0.01	0.12	0.22	0.11	0.02	0.23	0.01	0.02
Case No	10	11	12	13	14	15	16	17	18
1 yr	0.01	< 0.01	< 0.01	0.07	0.02	0.02	0.02	0.08	0.04
10 yr	0.01	< 0.01	< 0.01	0.14	0.05	0.05	0.05	0.17	0.09
Adults	0.02	< 0.01	< 0.01	0.25	0.09	0.09	0.09	0.31	0.16

Note)
- No simulation factors were used (24 h outdoors).
- Dose coefficients for Cs: Type F aerosols with AMAD of 1 μm
- A half air concentration value at the original location and destination was used during movements.
- A single grid value (the nearest grid) was used for each location.

Results of early internal doses (thyroid)

Location	Committed equivalent dose to thyroid (mSv) Adults	Children
Fukushima Prefecture		
Iitate	30 (90%), < 10 (50%)	20 (90%), < 10 (50%)
Kawamata	10 (90%), < 10 (50%)	10 (90%), < 10 (50%)
Iwaki city	...	20 (90%), < 10 (50%)
Namie	20 (90%), < 10 (50%)	30 (90%), < 10 (50%)
Minami-soma	...	...
Futaba, Okuma, Tomioka Naraha	20 (90%), 10 (50%)	30 (90%), < 10 (50%)
Hirono	20 (90%), < 10 (50%)	30 (90%), 20 (50%)
Kawauchi	< 10 (90%)	< 10 (90%)
Rest of Fukushima Pref.	...	...
Neighboring Prefectures	...	...

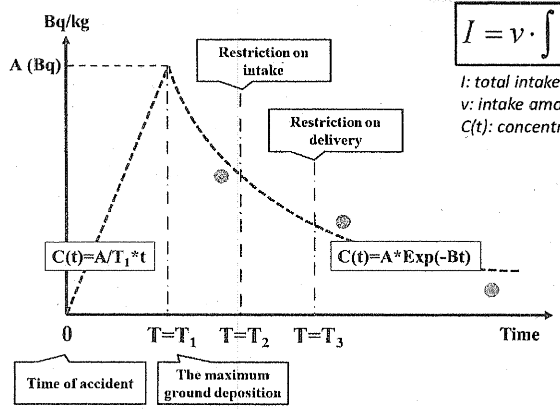
Red: from thyroid measurements, Blue: from WB measurements, Black: from simulations and other methods

N.B.)Doses in the table are given for residents of each municipality at the time of accident.

Ingestion

Ingestion model for internal dose estimations

- **Due to a possible wide variation of individual intake amounts by ingestion, the proposed model is limited to use for predicting critical groups.**



Assumed concentration profile for food and drink

$$I = v \cdot \int C(t) \cdot dt$$

I: total intake (Bq)
v: intake amount per day (kg/day)
C(t): concentration profile (Bq/kg)

Intake scenarios

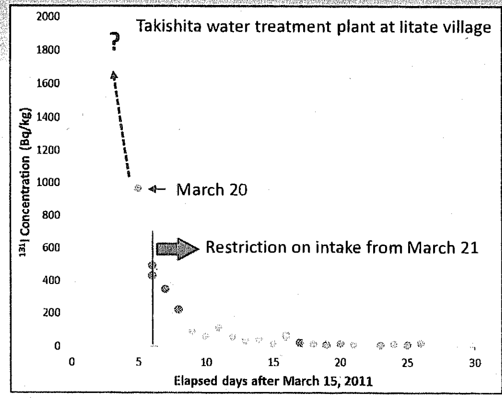
- **Scenario 1:** continue to intake until restrictions and then stop intake later.
- **Scenario 2:** the same as Scenario 1 other than restart intake after lifting restrictions.
- **Scenario 3:** continue to intake regardless of restrictions.

Provisional regulation values for food and drink

Radionuclide group	Food category	Provisional regulation value (Bq/kg)
Radioiodine	Drinking water	300 (100 for infants)
	Milk	300 (100 for infants)
	Vegetables except corns, tubers and roots	2000
	Seafood	2000
Radiocesium	Drinking water	200
	Milk	200
	Vegetables	500
	Cereals	500
	Meats, eggs, seafood and other foodstuff	500

- Only radioiodine and radiocesium are shown here.
- The provisional regulation values for radioiodine in seafood was set on 5 April 2011, but other values were set on 17 March 2011.

Radioactivity concentration of tap water



- Radioactivity measurements were not performed before March 20 for most districts.
- Ground deposition is expected to reach the maximum on March 15. Thus, radioactivity in drinking water was assumed to be the maximum on March 16.
- Extrapolation of measurement data would give a large uncertainty in the profile of radioactivity concentration.

Estimated thyroid doses by ingestion of tap water (1)

(mSv)

Municipality (Place of sampling)	Scenario 1 (March 12 – March 20 or 21)			Scenario 3 (March 12 – April 30)		
	Adults	Children	Infants	Adults	Children	Infants
Iitate village						
(Hanatsuka)	17	87	63	18	92	67
(Takishita)	24	120	88	25	130	93
(Tajiri)	3.5	18	13	5.0	25	18
(Okura)	< 1	2.6	1.9	< 1	4.5	3.3
Kawamata town						
(Chuokoen)	2.1	10	7.6	2.4	12	8.8
(Yakuba-Nishichosha)	1.6	7.9	5.8	1.7	8.9	6.5
Koriyama (Toyoda)	2.6	13	9.6	3.0	15	11
Minimisoma city						
(Hibari gakushu center)	3.4	17	13	4.0	20	15
(Godo-chosha)	9.0	46	33	9.3	47	35
Tamura city (City hall)	< 1	4.3	3.1	1.3	6.6	4.8
Iwaki city (Godo-chosha)	< 1	2.5	1.8	< 1	4.7	3.5

- Mean daily water intakes of adults, children (1 yr), infants are 1.65 L/d, 1 L/d and 0.71 L/d, respectively.
- Municipalities in the table announced restriction on intake of drinking water.

Estimated thyroid doses by ingestion of tap water (2)

(mSv)

Municipality (Place of water treatment plant or sampling)	Scenario 3 (March 12 – April 30)		
	Adults	Children	Infants
Hirono town	3.9	20	14
Miharu town	1.2	6.2	4.5
Sugakawa city	9.1	46	34
Nihonmatsu city	< 1	4.4	3.2
Soma district			
(Onodai)	1.0	5.1	3.8
Motomiya city	< 1	1.3	< 1
Ono town	< 1	2.3	1.7
Shirakawa	< 1	1.7	1.2
Fukushima			
(Genshiryoku center)	< 1	3.9	2.8
(Surikami)	< 1	3.1	2.2

- Mean daily water intakes of adults, children (1 yr), infants are 1.65 L/d, 1 L/d and 0.71 L/d, respectively.
- Municipalities in the table did not announce restriction on intake of drinking water.

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Discussion

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Limitations of WB measurement approach

- Distributions of thyroid doses from ^{131}I are assumed to be the same as those of effective doses from Cs.

- Uncertainty in the intake amount ratio of $^{131}I/^{137}Cs$
  - A likely ratio band: 5 ~10
  - The ratio is likely to vary with locations and exposure periods.

- Late WB measurements may include subjects with
  - incidental contamination on clothes/incidental intake events in existing situations.
  - resulting in overestimations of estimated thyroid; the dose distribution may become wider...

- Predicted median values of CEDs include mathematical error.

- Intake via inhalation only.

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Limitations of simulation approach

- The simulation would give a certain prediction within observed bands for thyroid doses (I-131) or CEDs (Cs).
  - Likely to overestimate observed thyroid doses (90%-tile values).
  - Reasonable estimations for CEDs from Cs?

- The validation of the simulation for internal dose estimates is still a on-going task.
  - More comparisons between observed and calculated doses are needed.
  - Set reasonable simulation factors (indoor, ventilation rate, ...).

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Ingestion from tap water?

- Screening survey on thyroid doses of children in Iitate suggests that ingestion from tap water is much lower than that predicted.

- This discrepancy is probably caused by ...

  - Actual intake of tap water is very small. (Drink bottled water instead?) → This can be cleared by personal interview.

  - An inappropriate profile of radioactivity concentration. → Consider a precise trend of ground deposition, a dynamics model for radioactive concentration, ...

- The above reasons should be carefully examined.

Thank you very much for your kind attention!!

Additional information on human measurements

Published information on human measurements (1)

Journal of Environmental Radioactivity 110 (2012) 84–89

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Radiation doses among residents living 37 km northwest of the Fukushima Dai-ichi Nuclear Power Plant

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[d] Research Institute for Radiation Biology and Medicine, Hiroshima University, 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8553, Japan

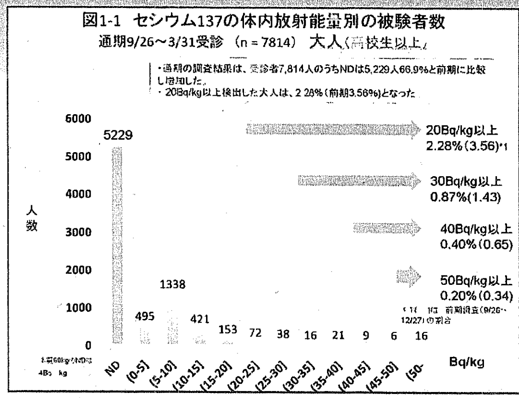
Table 2
Cumulative effective dose up to 54 d, committed effective dose from ^{134}Cs and ^{137}Cs and equivalent dose for thyroid gland from ^{131}I.

Subject	M/F	Age	Bodyweight (kg)	Cumulative effective dose[a] (mSv)	Committed effective dose[b]			Equivalent dose (thyroid)
					^{134}Cs (mSv)	^{137}Cs (mSv)	Cs total (mSv)	^{131}I (mSv)
(Adult Group)								
G1	M	77	57	8.7	0.065	0.044	0.110	66
G2	F	76	53	7.9	0.044	0.033	0.077	58
G6	F	61	68	7.0	0.051	0.036	0.087	ND
G7	M	59	63	11.2	0.026	0.005	0.032	ND
G8	M	68	53	8.4	0.023	0.014	0.037	ND
G9	M	54	65	6.6	0.011	0.014	0.025	ND
G10	M	36	75	7.6	0.010	0.012	0.022	ND
G11	F	29	49	8.2	0.012	0.007	0.018	ND
G13	M	54	61	10.0	0.014	0.008	0.022	ND
G14	F	65	55	7.0	0.062	0.039	0.101	50
G15	M	59	61	10.3	0.049	0.024	0.073	27
Average				8.4	0.033	0.021	0.055	50
(Child group)								
G3	M	14	48	5.4	0.022	0.014	0.036	44
G4	F	12	40	5.4	0.021	0.015	0.036	ND
G5	M	10	30	5.6	0.020	0.016	0.037	ND
G12	M	4	17	3.9	0.004	0.003	0.007	ND
Average				5.1	0.017	0.012	0.029	44

[a] Errors to be 10%.
[b] Errors to be 12%.

Intake scenario: a single intake via ingestion on March 20, 2011

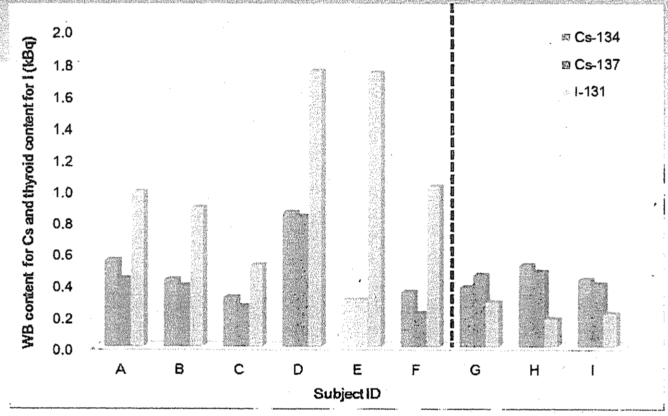
Published information on human measurements (2)



- http://www.city.minamisoma.lg.jp/shinsai2/kensa/hibakukenshinkeka.jsp
- http://www.city.minamisoma.lg.jp/shinsai2/kensa/hibakukenshinkeka2.jsp
- http://www.city.minamisoma.lg.jp/shinsai2/kensa/hibakukenshinkeka3.jsp
- M. Tsubokura et al., JMMA, 308, 669-670 (2012).

- Minamisoma city has independently carried out WB measurements of residents since July 11, 2011 and periodically has published results of the measurements.

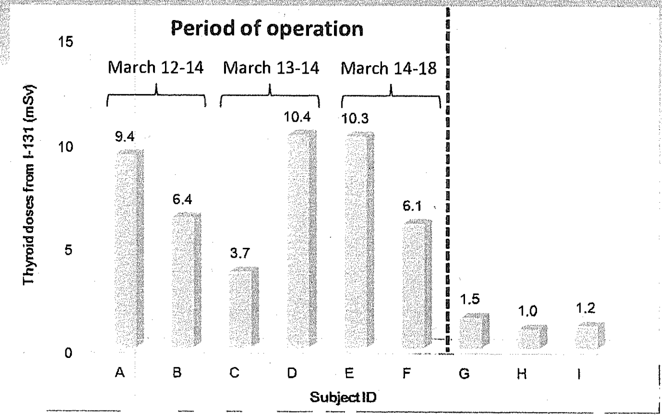
Analysis of WB measurements of JAEA workers (1)



- Contents with decay correction (March 29, 2011)
- Cs contents of Subject E are not detected. Typical MDA values of 300 Bq are shown instead.

Subjects A-F: Workers in charge of emergency radiological monitoring at neighboring sites of FDNPS at the early state of the accident (March 12 ~). They were measured with a standing-type WBC.
Subjects G-I: Others (Subject G visited Fukushima city from night on March 15 to March 18). They were measured with a chair-type WBC installed in a shielded room and a NaI(Tl) spectrometer.
All the subjects are employees of JAEA Tokai research center (Ibaraki Prefecture).

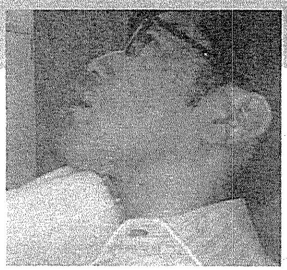
Analysis of WB measurements of JAEA workers (2)



- Intake scenario for internal dose estimations: a single intake via inhalation on the first day of operation or March 15.

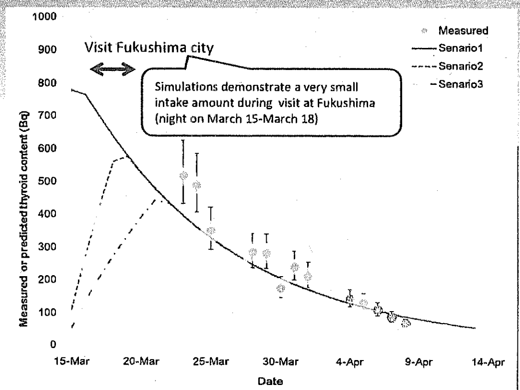
- The body content of ^{131}I is significantly higher for the first responders than for the others.
- Thyroid doses of the first responders > Thyroid doses of evacuees ?

Analysis of WB measurements of JAEA workers (3)



Subject G

(Thyroid measurement with a NaI spectrometer)

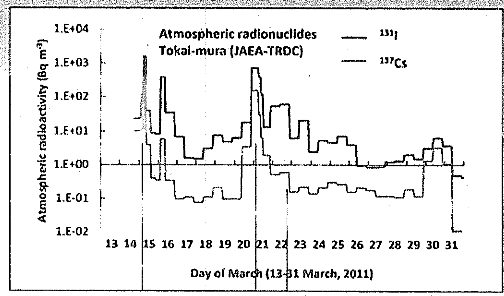


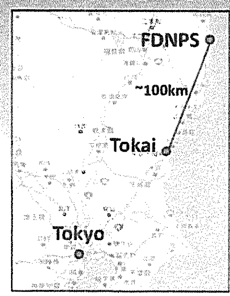
Intake scenario	Intake activity (Bq)	Thyroid dose (mSv)
Single intake on Mar 15	3400	1.3
Repeated intake from Mar 15 to Mar 18	2800 (710 d^{-1})	1.1
Repeated intake from Mar 15 to Mar 21	2400 (240 d^{-1})	0.9

Assumed physicochemical form: vapor (SR-1, Type F)

Compare integrated air concentration at JAEA Tokai site

Analysis of WB measurements of JAEA workers (3)





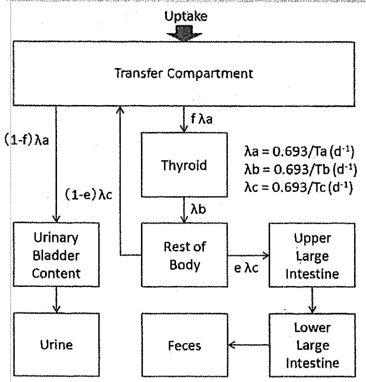
(Tsuruta et al, NIRS proceedings)

Intake amount via inhalation estimated from air sampling (up to March 31)
- **^{131}I: 18000 Bq**
  (vapor: 10000 Bq, particle: 8000 Bq)
- **^{137}Cs: 2300 Bq**

Intake amount via inhalation estimated from human measurements (3 subjects)
- **^{131}I: ~3000 Bq (15%)**
- **^{137}Cs: ~1500 Bq (65%)**

- Intake amount is much smaller than that expected from air concentration for iodine...

ICRP's Biokinetic model for iodine



Biokinetic model parameters proposed by ICRP

Age	f1	f: Uptake to thyroid (%)	e: Faecal excretion (%)	Blood Ta (d)	Thyroid Tb (d)	Rest of body Tc (d)
3 mo	1	30	20	0.25	11.2	1.12
1-y	1	30	20	0.25	15	1.5
5-y	1	30	20	0.25	23	2.3
10-y	1	30	20	0.25	58	5.8
15-y	1	30	20	0.25	67	6.7
Adult	1	30	20	0.25	80	12

Ref.) ICRP Publications 56 and 30

Iodine uptake of the thyroid gland for Japanese

Authors	Subject number	Uptake rate	Age of cases
Nakagawa (1959)	85	0.22	from 3 to 10 yr
Nakamura (1966)	31	0.21	adult
Nakamura (1965)	47	0.12	adult
Kubo (1958)	31	0.25	child
Koshiyama (1962)	81	0.17	from 10 to 49 yr
		0.19	from 50 to 79 yr
Okabe (1961)	80	0.23	from 3 to 17 yr
Kinoshita (1966)	400	0.21	over 10 yr
Ishizuki (1960)	77	0.22	under 49 yr
		0.17	over 50 yr
Fujita (1962)	197	0.19	
Iino (1958)	17	0.19	from 22 to 33 yr

Ref.) Yoshizawa and Kusama, J. Health. Phys. 11, 123-128 (1976)