Development of gamma camera for visualization of radioactive cesium to support Fukushima people recovering from the nuclear disaster

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Contents

Introduction

Job carrier of radiation and radioisotopes

Accident of nuclear power plant in Fukushima

Decontamination from residential area

Development of gamma camera

Prospect for the future

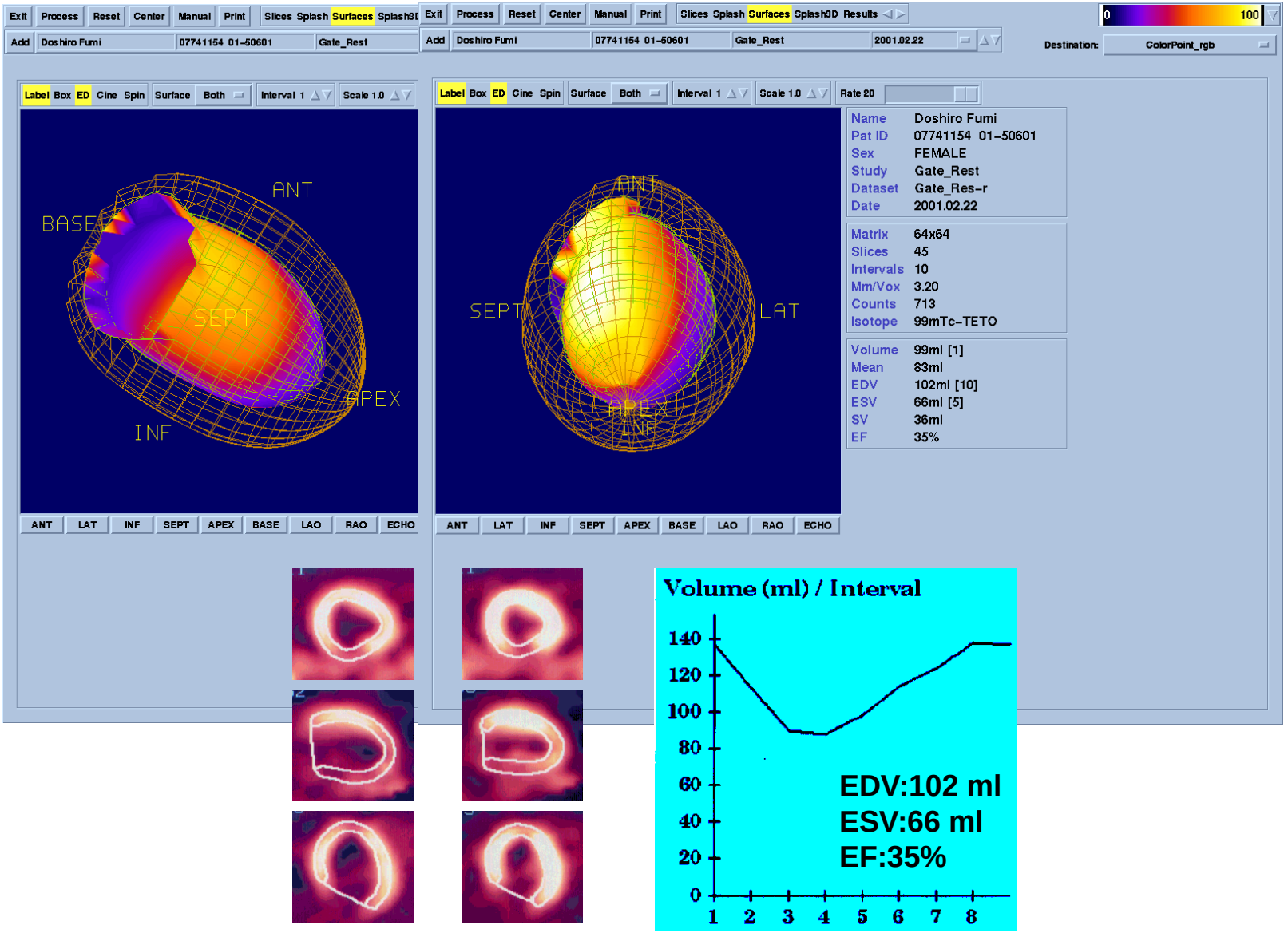
Dr. Hideki Yukawa (1907-1981)
Nobel laureates for Physics 1949 for prediction of meson

Faculty of Science students in 1963

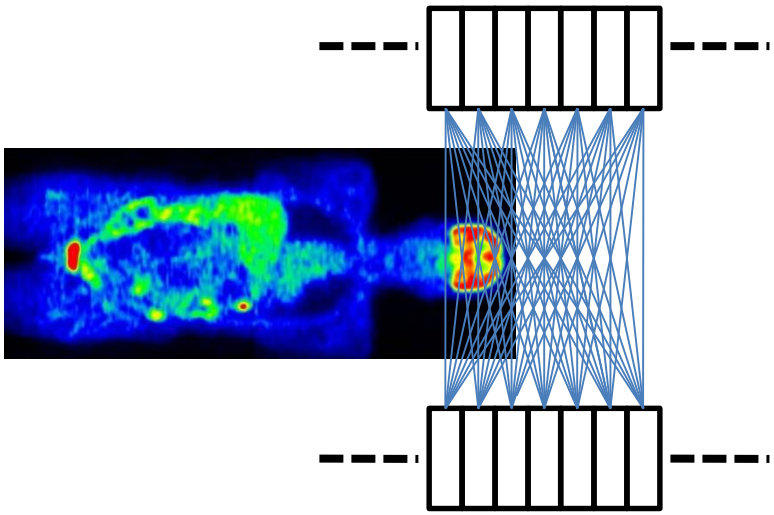
Working in the field of radiation and radioisotopes

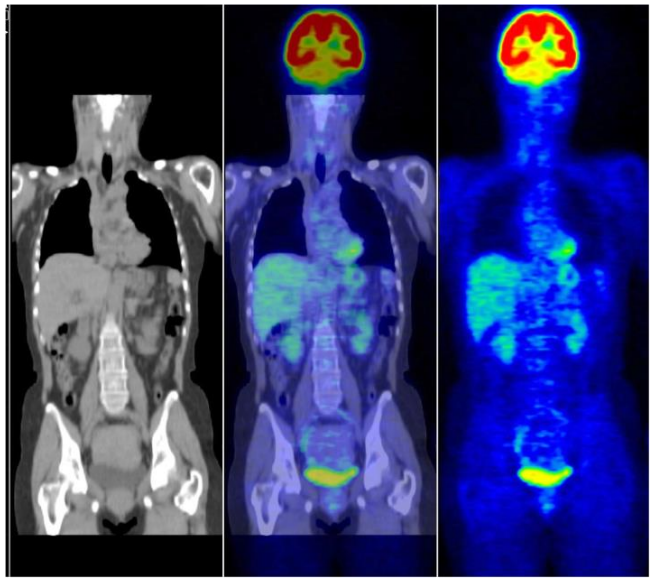
- Nuclear medicine for diagnosis of disease using gamma camera and radiopharmaceuticals which emit gamma rays
- In 1960's, radiopharmaceuticals industry started in Japan establishing JV companies with USA, UK and French partners
- Manufacturing radiopharmaceuticals and protecting workers from radiation hazards

SPECT of cardiac muscle motion

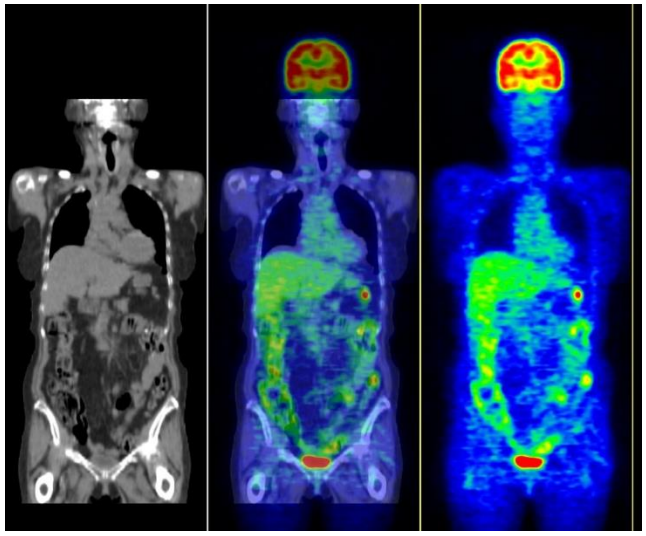


Clinical PET-CT : Glucose metabolism

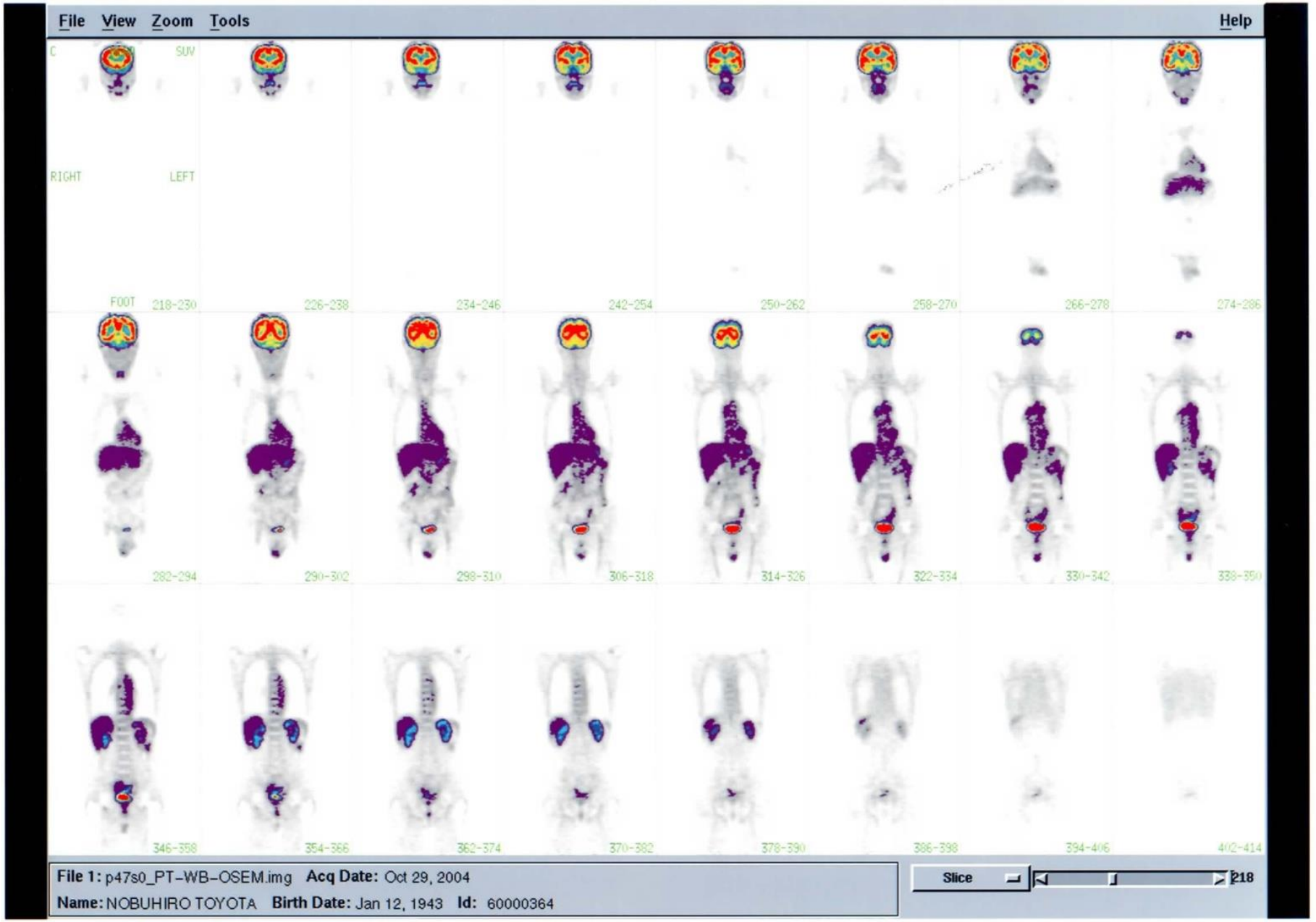




CT PET-CT PET



PET scanning of N. Toyota



Fear for invisible radiation

- **Limit of occupational radiation dose in 1970's;**
  3 rem (30 mSv) per quarter (3 months)
  Accumulated dose= 5 rem (N-18)
- **Repairing cyclotrons and handling radioisotopes gave 13.4 rem (134mSv) of total accumulated dose for 10 years**
- **National license for radiation health physicist**
- **Dilemma of increasing production and radiation control of employees**

撮影＝中宮美佐男

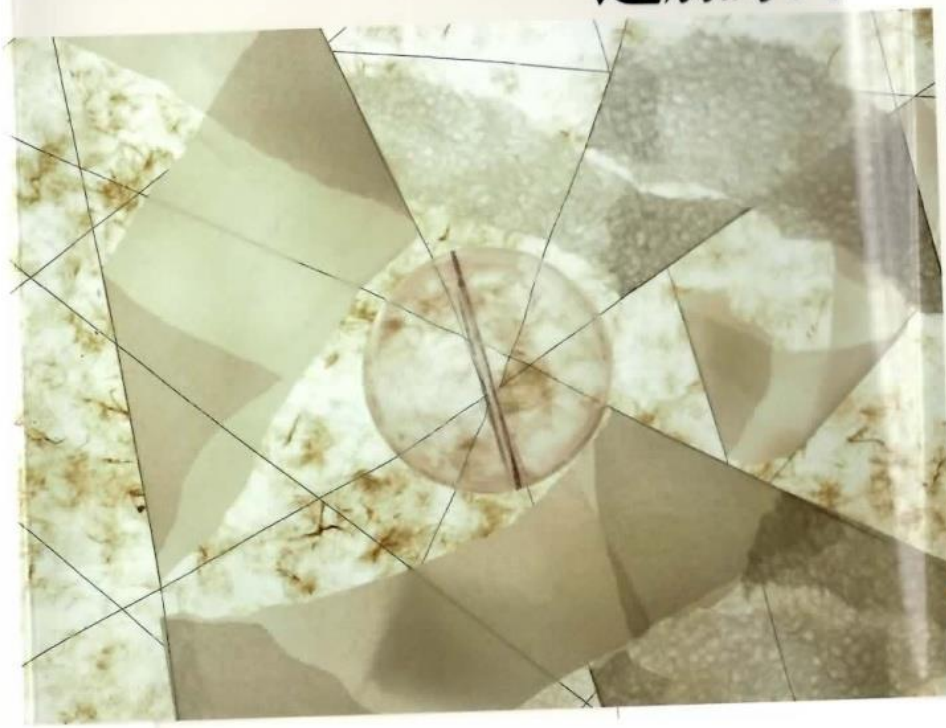
こんどう・そうへい　一九三二年福岡県生まれ。京都大学理学部卒。遺伝学研究所室長、大阪大学医学部放射線基礎医学教授、近畿大学原子力研究所教授を経て、現在、大阪大学名誉教授、近畿大学原子力研究所特別研究員。この間、物理学から遺伝学、基礎医学に転進し、国際的に活躍。高松宮妃癌研究基金学術賞、日本遺伝学会木原賞、講談社出版文化賞科学出版賞、放射線影響協会江藤記念賞、国際光生物学会フィンセン・メダル各受賞。『分子放射線生物学』『生命を考える』『低レベル放射線の健康影響（英文著書）』ほか編・著書は数多い。

BLUE BACKS

人は放射線になぜ弱いか 第3版

少しの放射線は心配無用

近藤宗平



人は放射線になぜ弱いか 第3版

少しの放射線は心配無用

近藤宗平

B1238

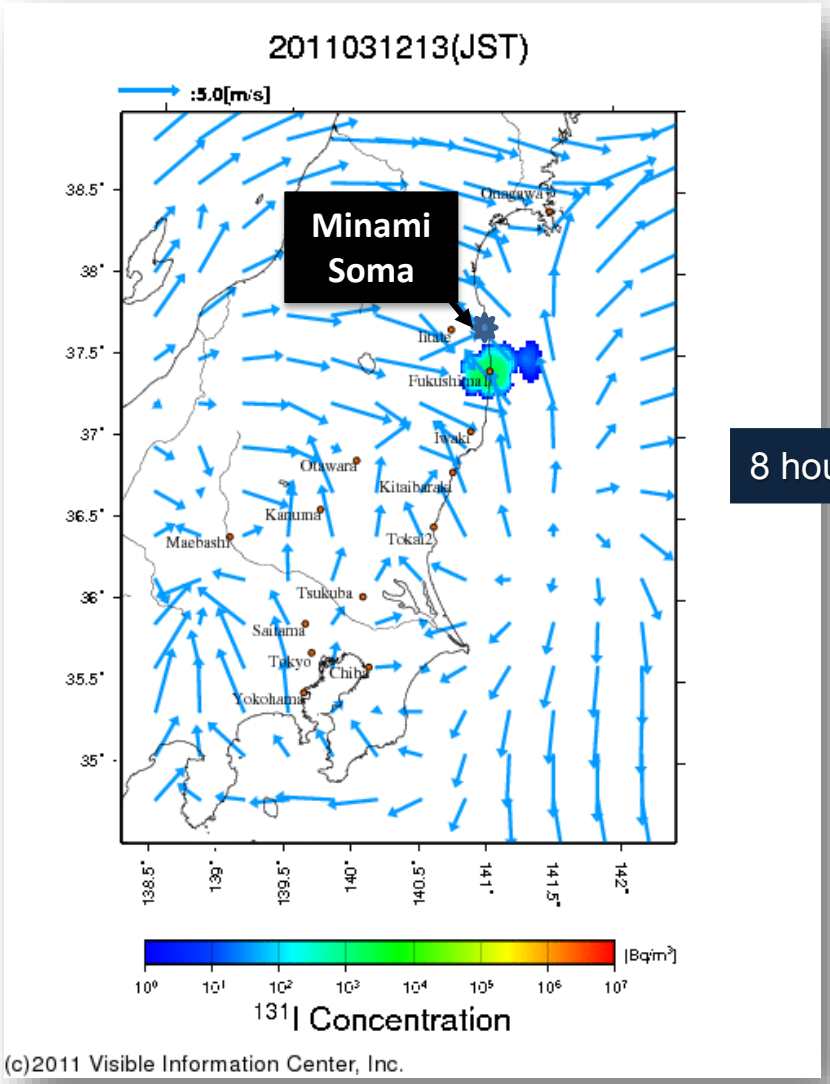
講談社

Y980

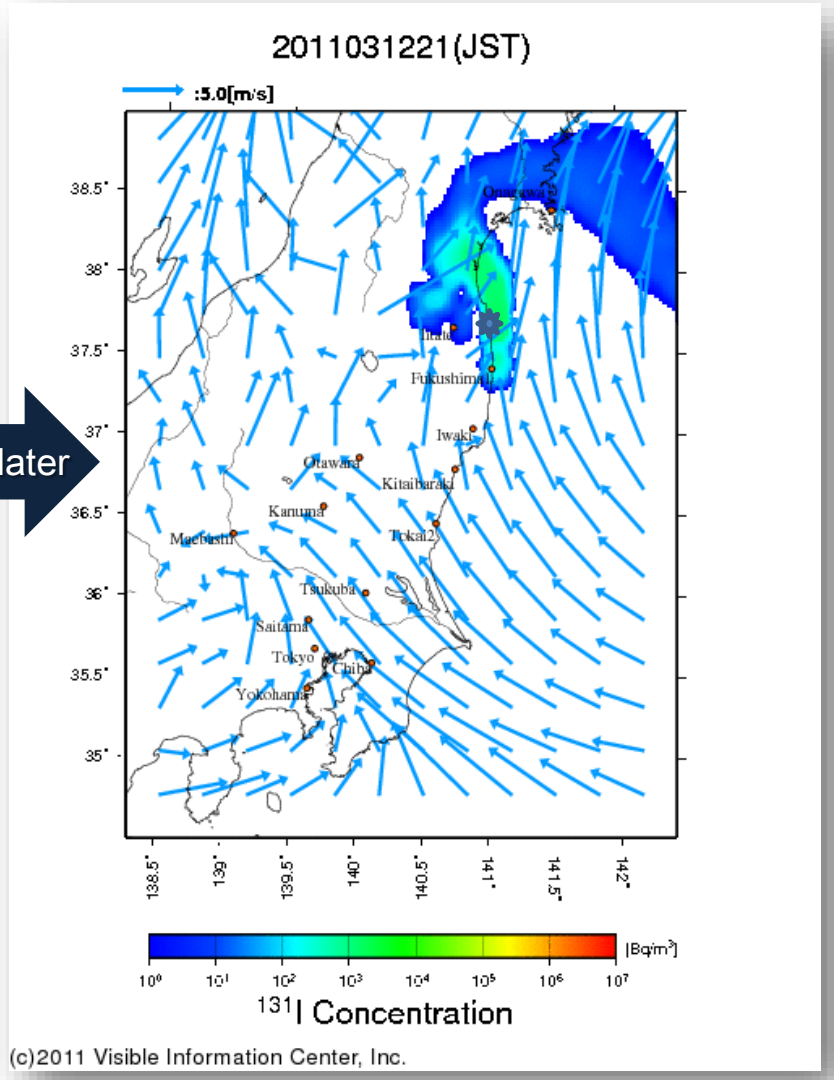
TEPCO 1F before the accident

In March 11, 2011
Fukushima Facility No. 1 (1F) of Tokyo Electric Power Company (TEPCO) was attacked by the earthquake and subsequent tsunami loosing all the electric power and resulting in melt down of nuclear fuels at unit 1, 2 and 3

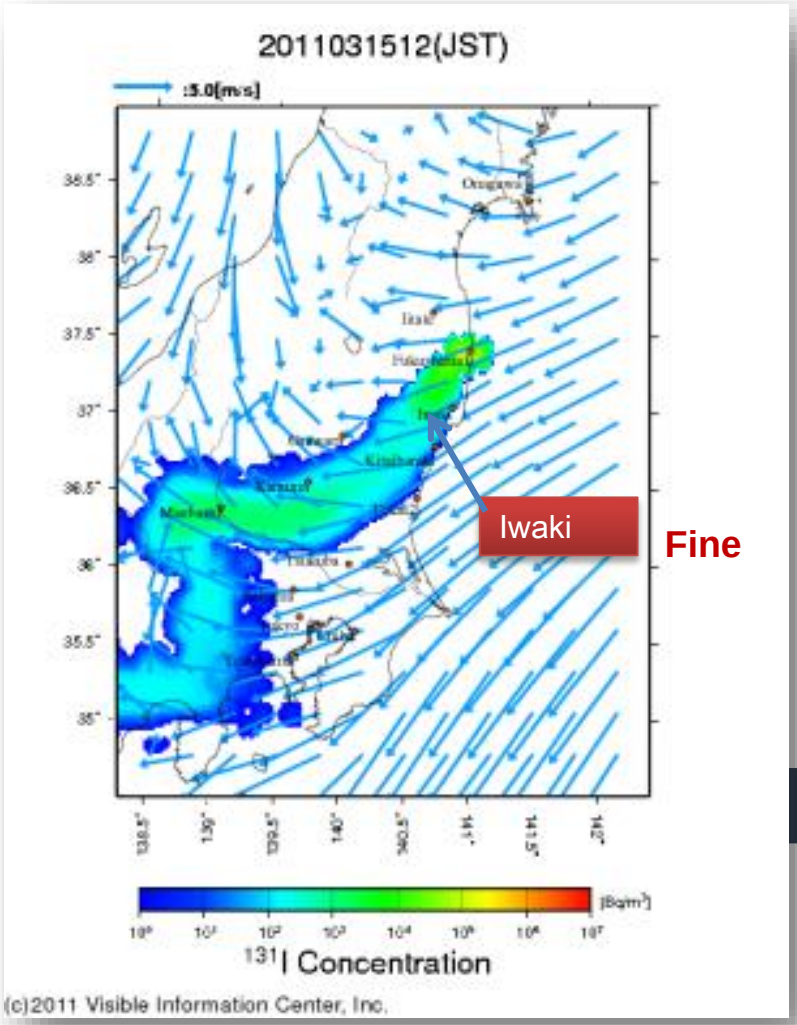
Plume March 12, 2011



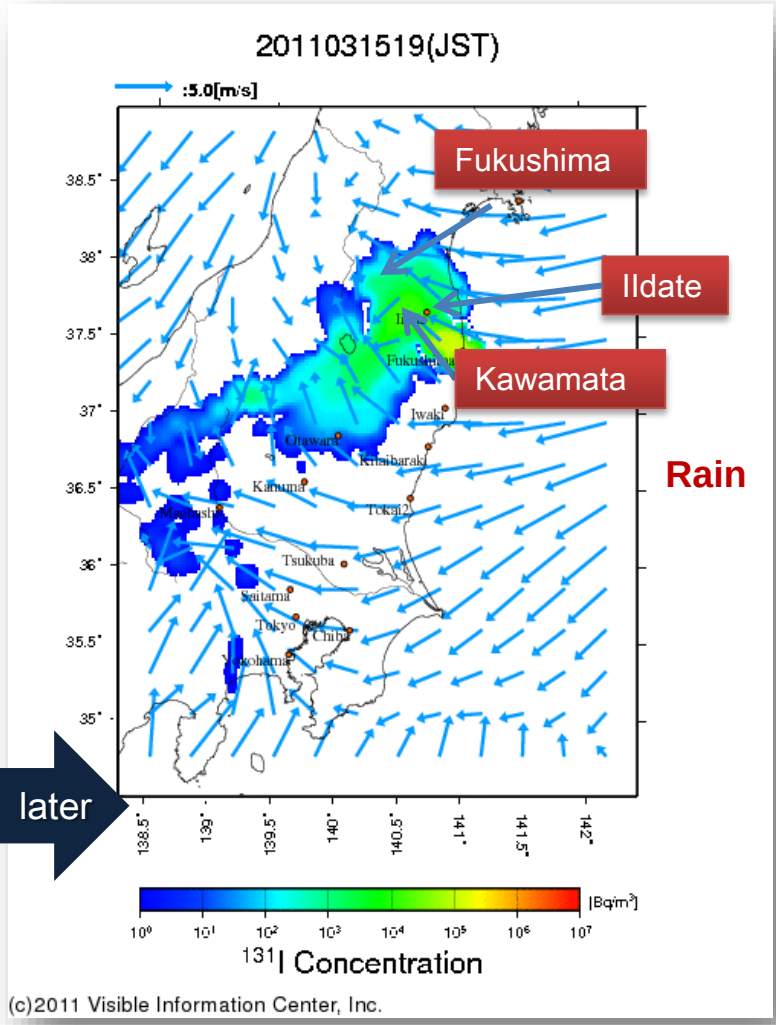
8 hours later

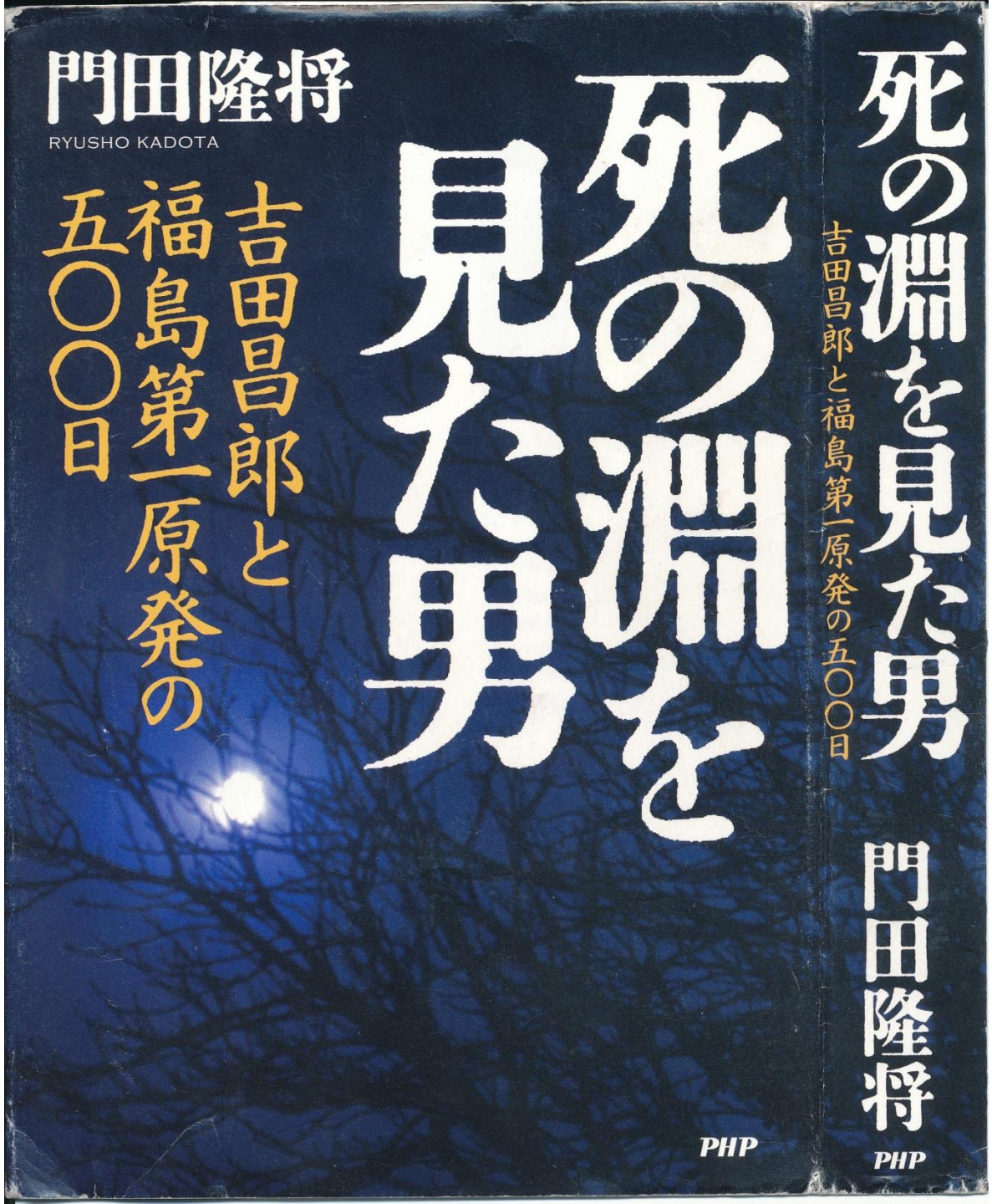


Plume March 15, 2015

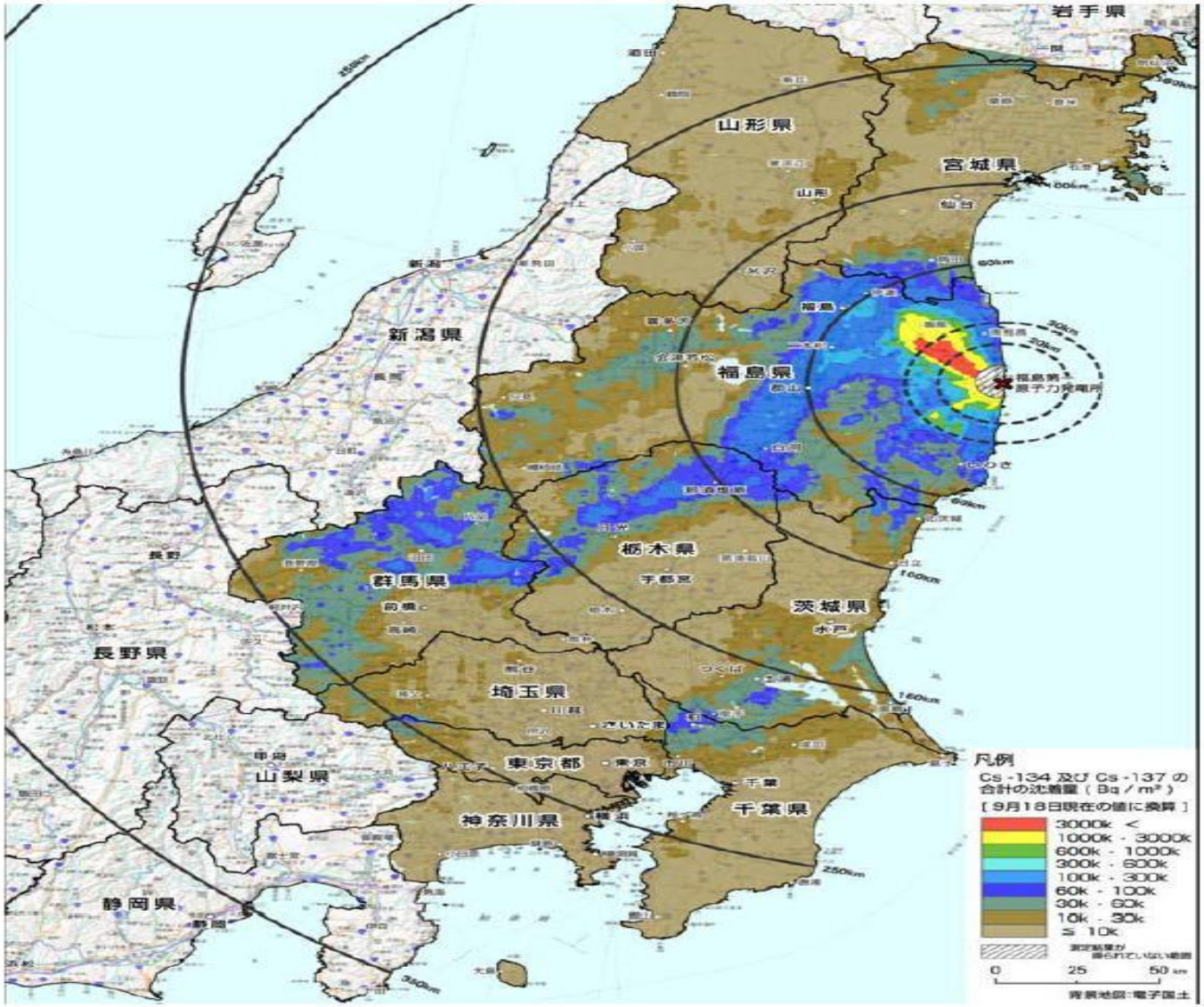


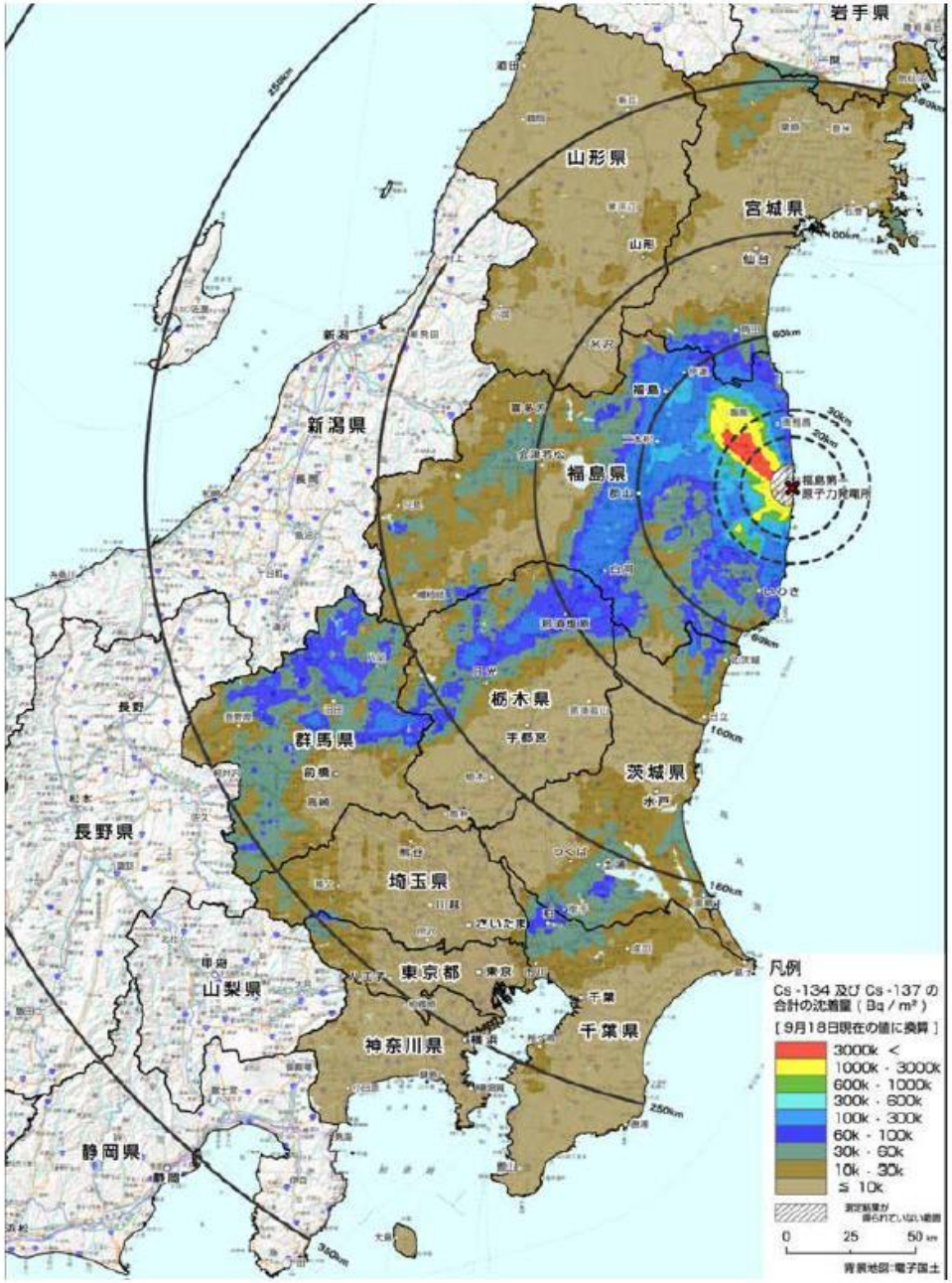
7 hours later

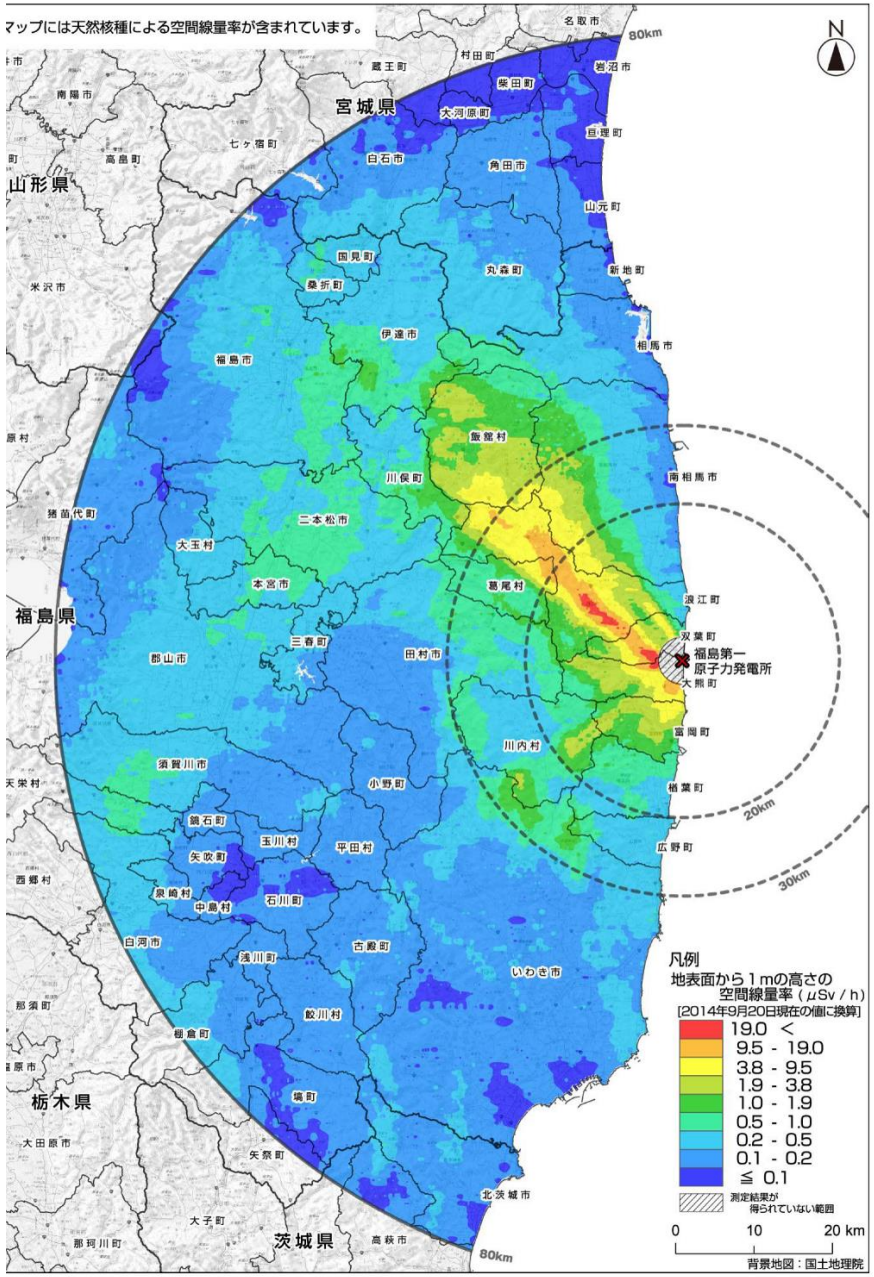


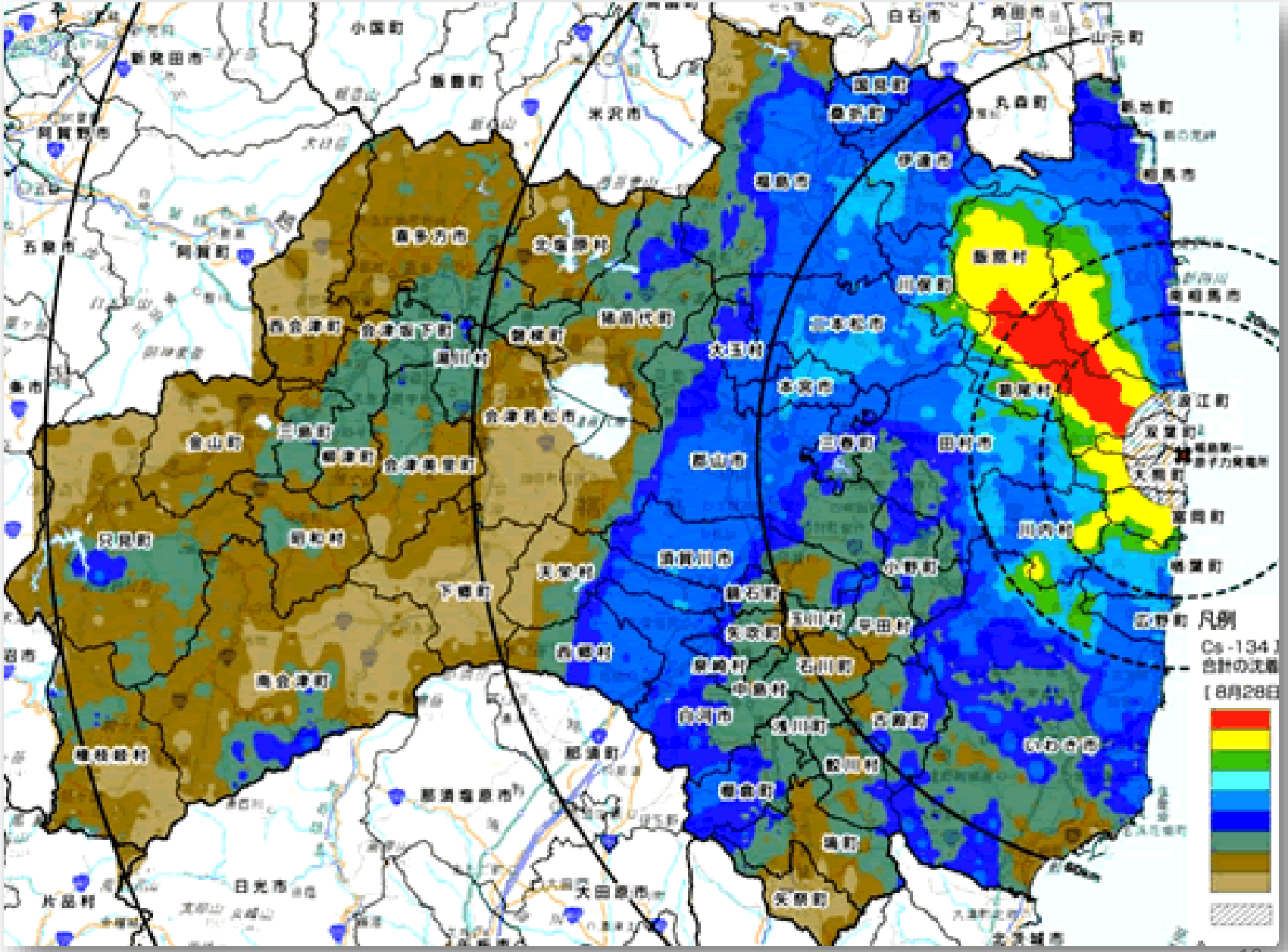

門田隆将
RYUSHO KADOTA
死の淵を見た男
吉田昌郎と福島第一原発の五〇〇日
PHP
死の淵を見た男
吉田昌郎と福島第一原発の五〇〇日
門田隆将
PHP

The worst scenario once postulated in March 2015

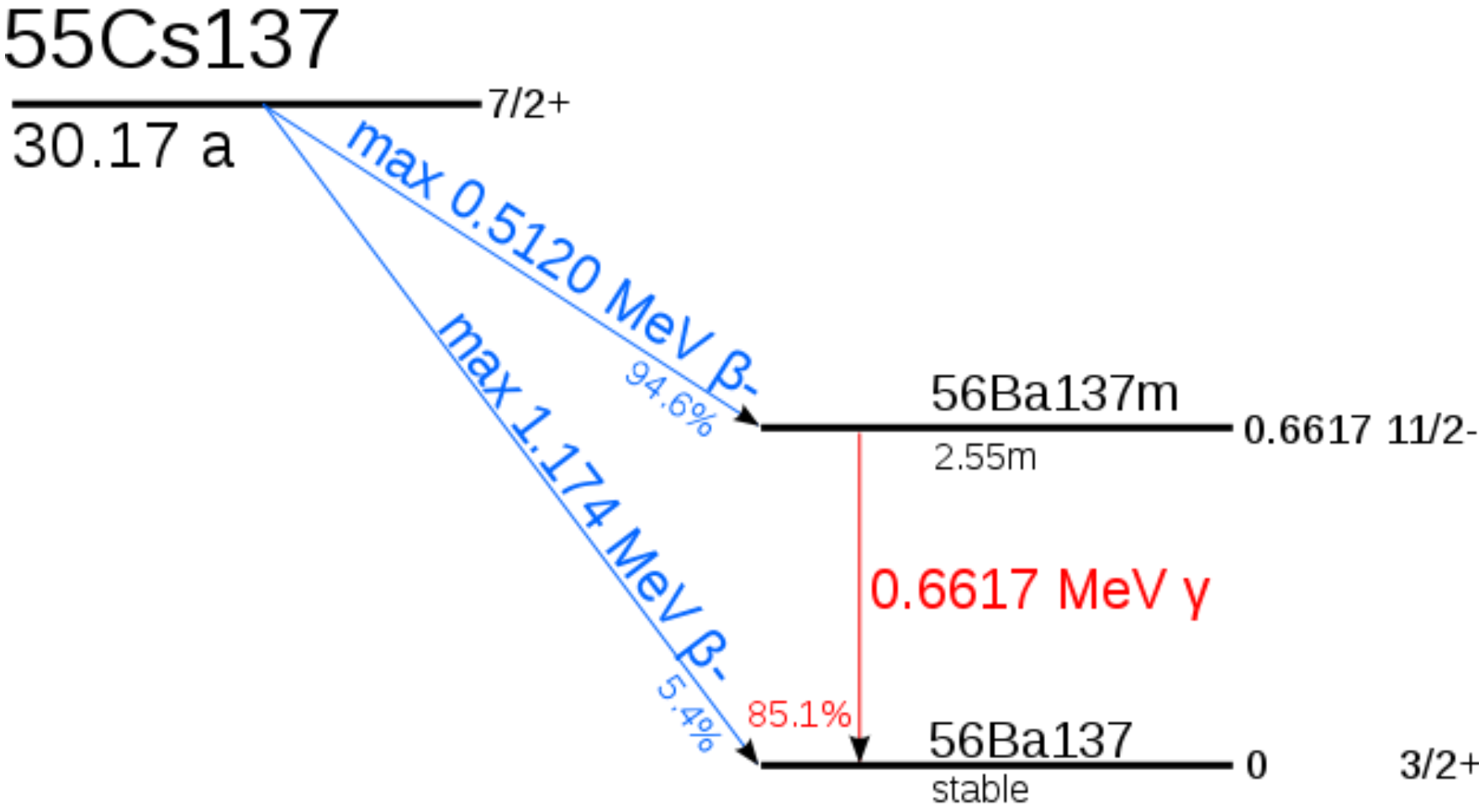



岩手県
山形県
宮城県
新潟県
福島県
栃木県
群馬県
茨城県
長野県
埼玉県
東京都
山梨県
千葉県
神奈川県
静岡県
福島第一
原子力発電所
凡例
Cs-134 及び Cs-137 の
合計の沈着量（Bq/m²）
［9月18日現在の値に換算］
3000k ＜
1000k - 3000k
600k - 1000k
300k - 600k
100k - 300k
60k - 100k
30k - 60k
10k - 30k
≦ 10k
測定結果が得られていない範囲
0 25 50 km
背景地図：電子国土

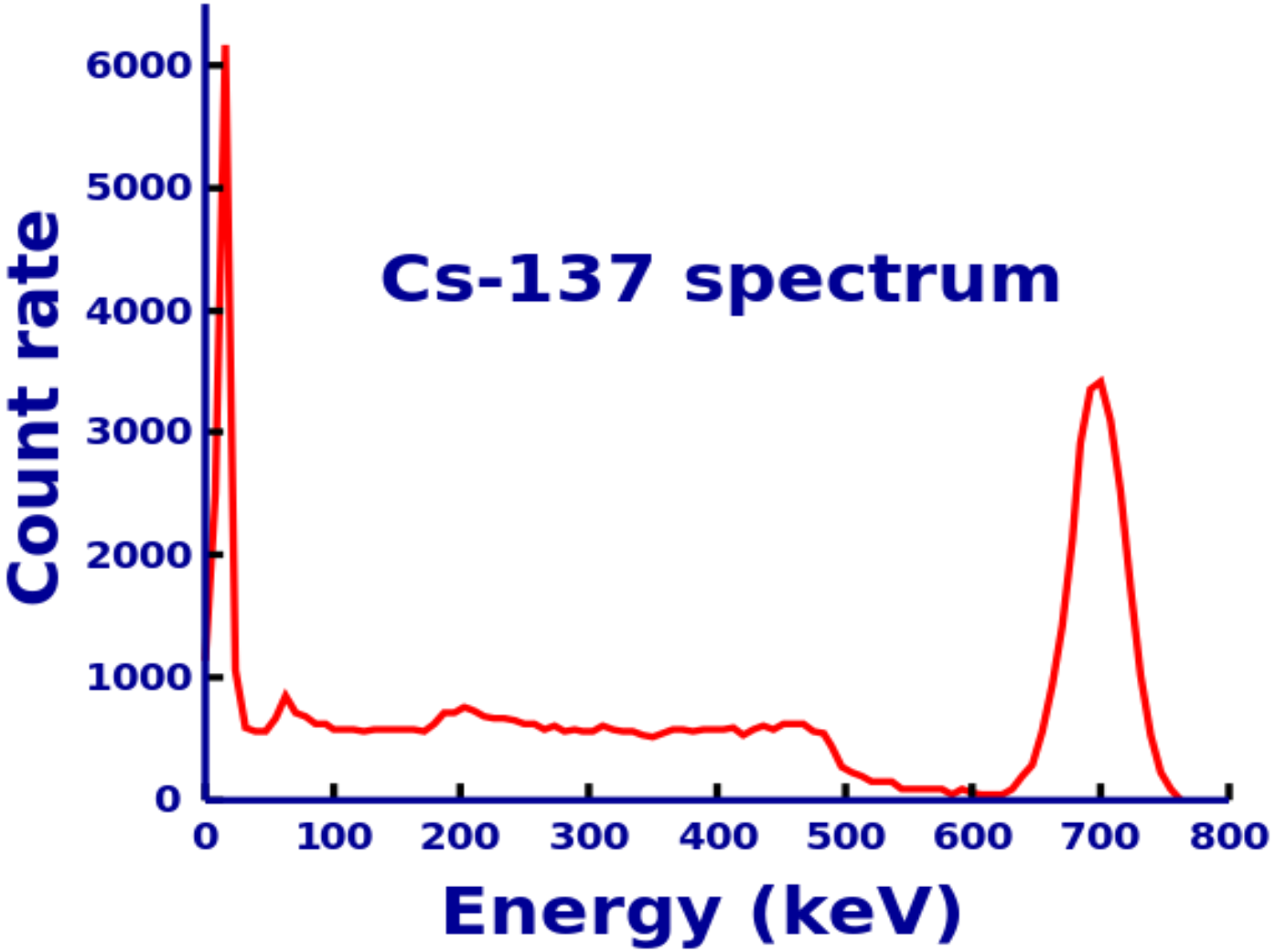

マップには天然核種による空間線量率が含まれています。
N
宮城県
山形県
福島県
栃木県
茨城県
福島第一
原子力発電所
凡例
地表面から1mの高さの
空間線量率（μSv/h）
［2014年9月20日現在の値に換算］
19.0 ＜
9.5 - 19.0
3.8 - 9.5
1.9 - 3.8
1.0 - 1.9
0.5 - 1.0
0.2 - 0.5
0.1 - 0.2
≦ 0.1
測定結果が得られていない範囲
0 10 20 km
背景地図：国土地理院


凡例
Cs-134
合計の沈着
[8月28日

Cs-137 Decay Scheme



Cs-137 gamma ray spectrum



Basic principles of Japanese government under the Act

- Area where additional exposures over 20mSv/y: Aim at stepwise and rapid reduction of those areas based on the ICRP recommendation (2007)
- Area where additional exposures less than 20mSv/y: As a long term goal, aim at reducing to 1mSv/y
- The goal to be reviewed periodically

Decontamination of the roof

Water jet is applied to clean up the surface of roof tiles

Recovering contaminated water into the tank

Contaminated water is carried out and filtered with zeolite column at waste water center.

Decontamination of houses and gardens

The surface soil of the garden is removed and cleaned by hands since machine cannot be used due to obstacles

Decontamination of house back yard

Radioactive wastes and contaminated soils are put into flexible container bags and moved to the temporary store place

The ground is covered with clean soil after shaved for 5 cm of the surface.

No operation in winter time


安全帯を使用せよ

Temporal storage area of contaminated soils, wastes and debris in Hirono town, Fukushima prefecture


0.283
μSv/h
0.559
DETECTOR
POWER


0.287
μGy/h
DETECTOR
0.559
μSv/h
BUZZER
POWER

Off limit area

Barriers to stay on the main road, route #6

Tomioka station and vicinity after four years of the casualty

Development of gamma cameras to get radiograph of gamma rays emitted from Cs-137 (plus Cs-134)

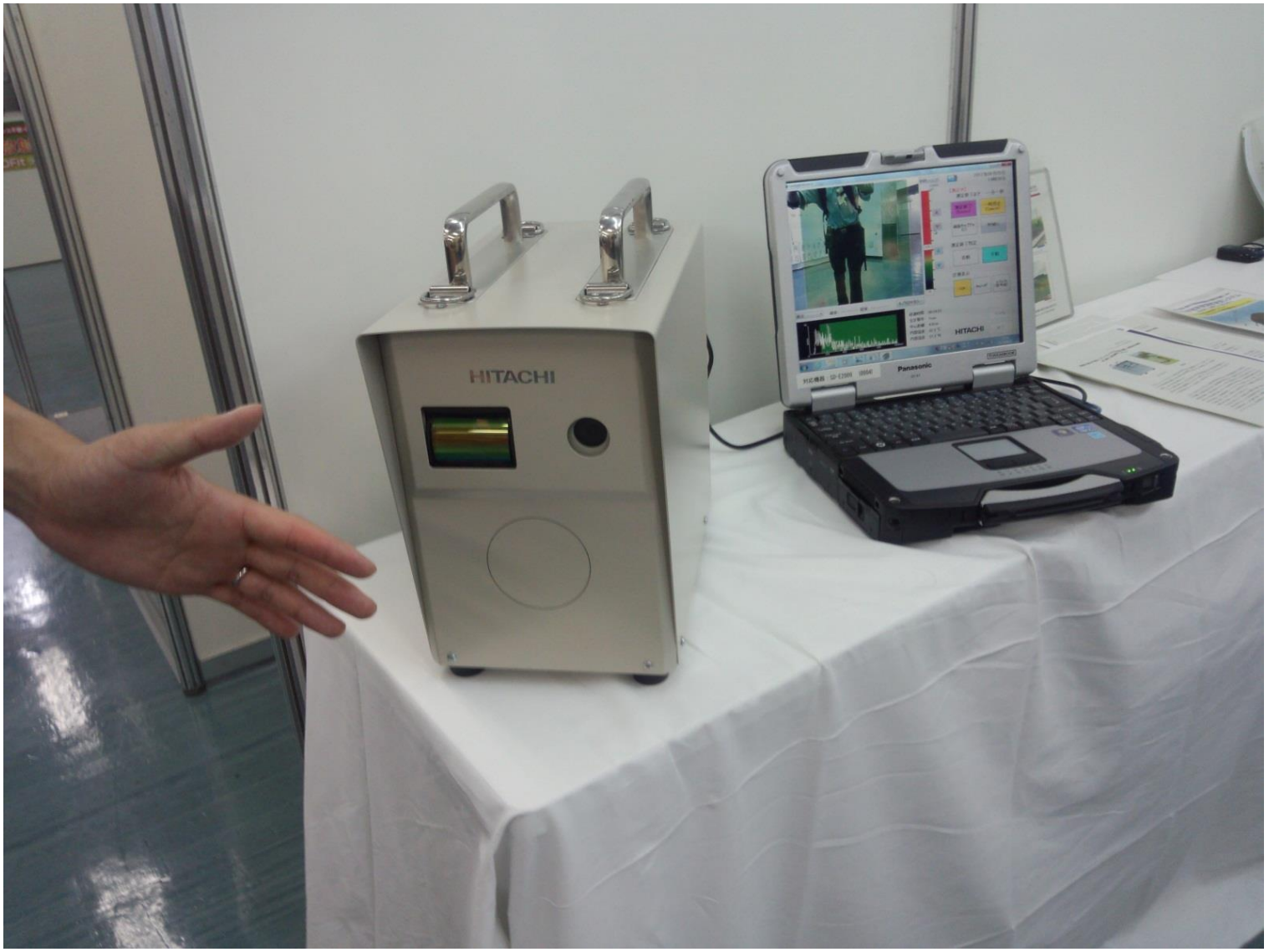
First generation: Pin hole collimator type

Second generation: Compton scattering type

Third generation: Coded aperture type

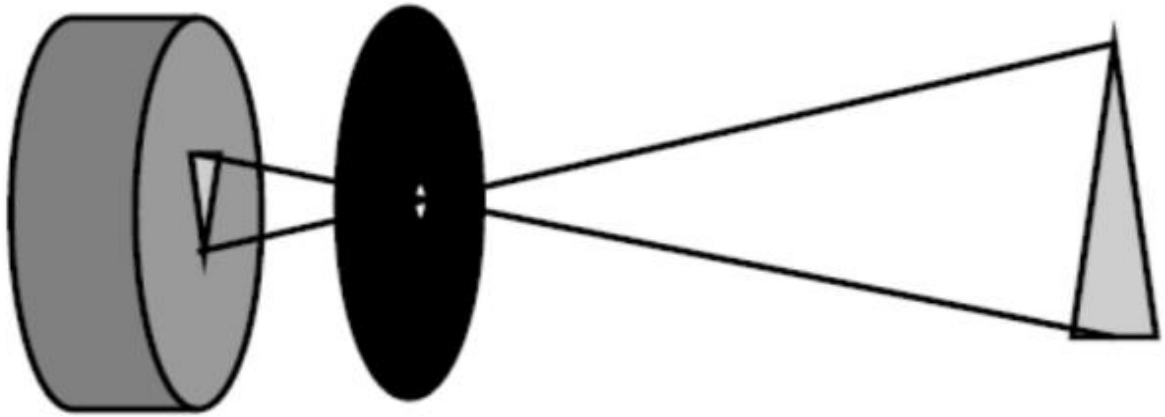
Fourth generation: Multiple pin holes type

Toshiba gamma camera with pin hole collimator



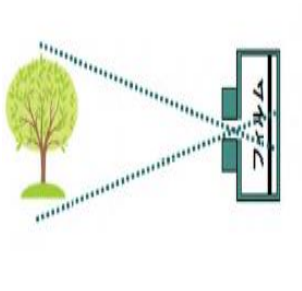
Pin hole type

- **Size of hole: Balance of incident photons and resolution**
- **Issue 1 : Artefact i.e., ghost image**
- **Issue 2 : Long capturing time (20-40 min)**
- **Issue 3 : Heavy weight 30 kg not able to carrying by one person**



Gamma ray visualization

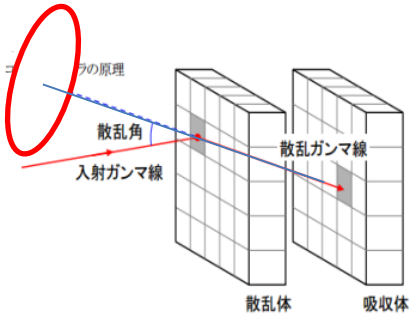
Pinhole type



Simple method

1. Long capturing time with small incident photons
2. Poor positional resolution
3. Artifacts
4. Heavy shielding: 35 kg

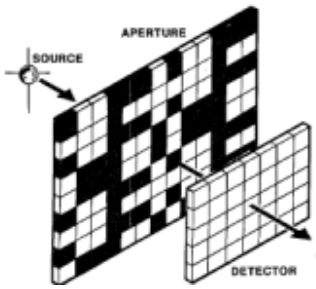
Compton-scatter type

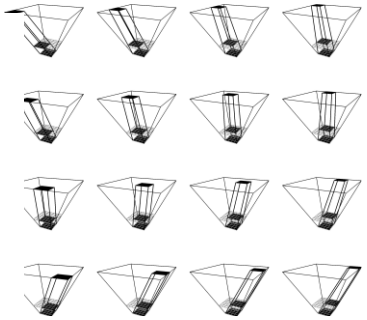


Direction of an incident ray being calculated by Compton scattering of photon and electron loss energy

1. Difficult to get image when many incident photons cattering hit on detector
2. Artifacts
3. Light weight with no shielding: 2kg

Coded-mask type

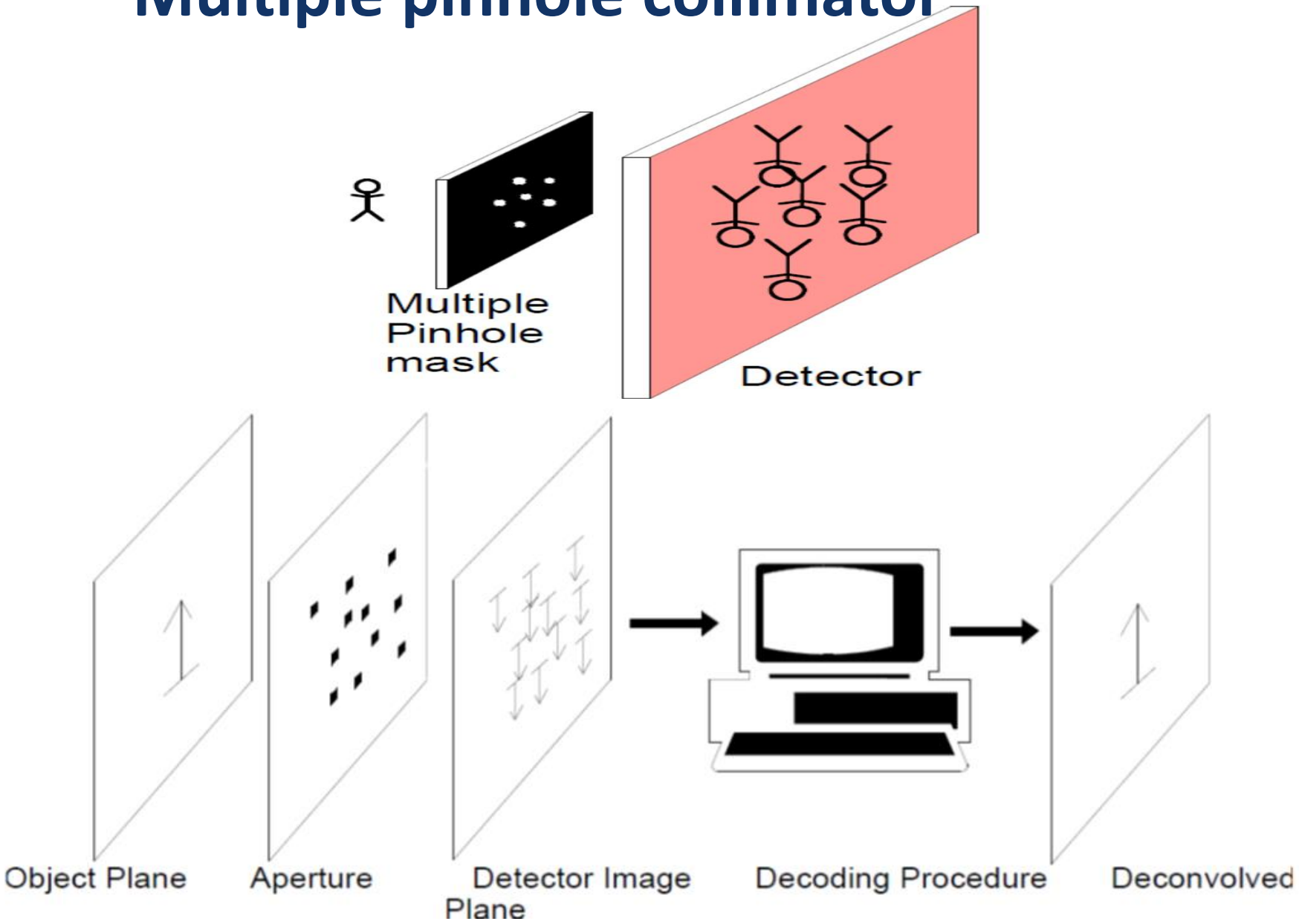




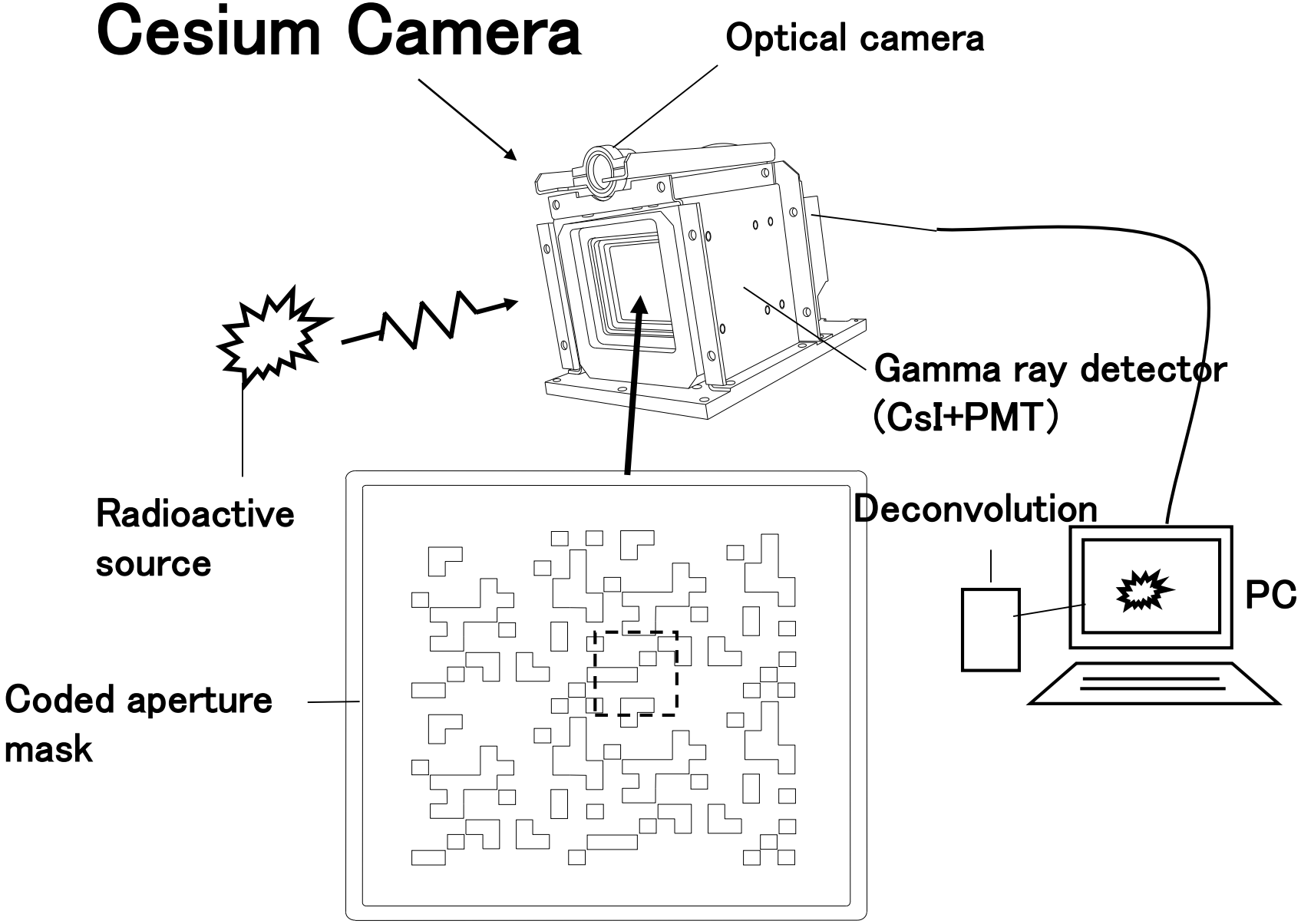
Direction of an incident ray calculated by optical patterns of passing through Mask

1. Short capturing time with many photons coming in through aperetures
2. Artifacts cancelled
3. Middle weight: 20 kg

Multiple pinhole collimator



Cesium Camera

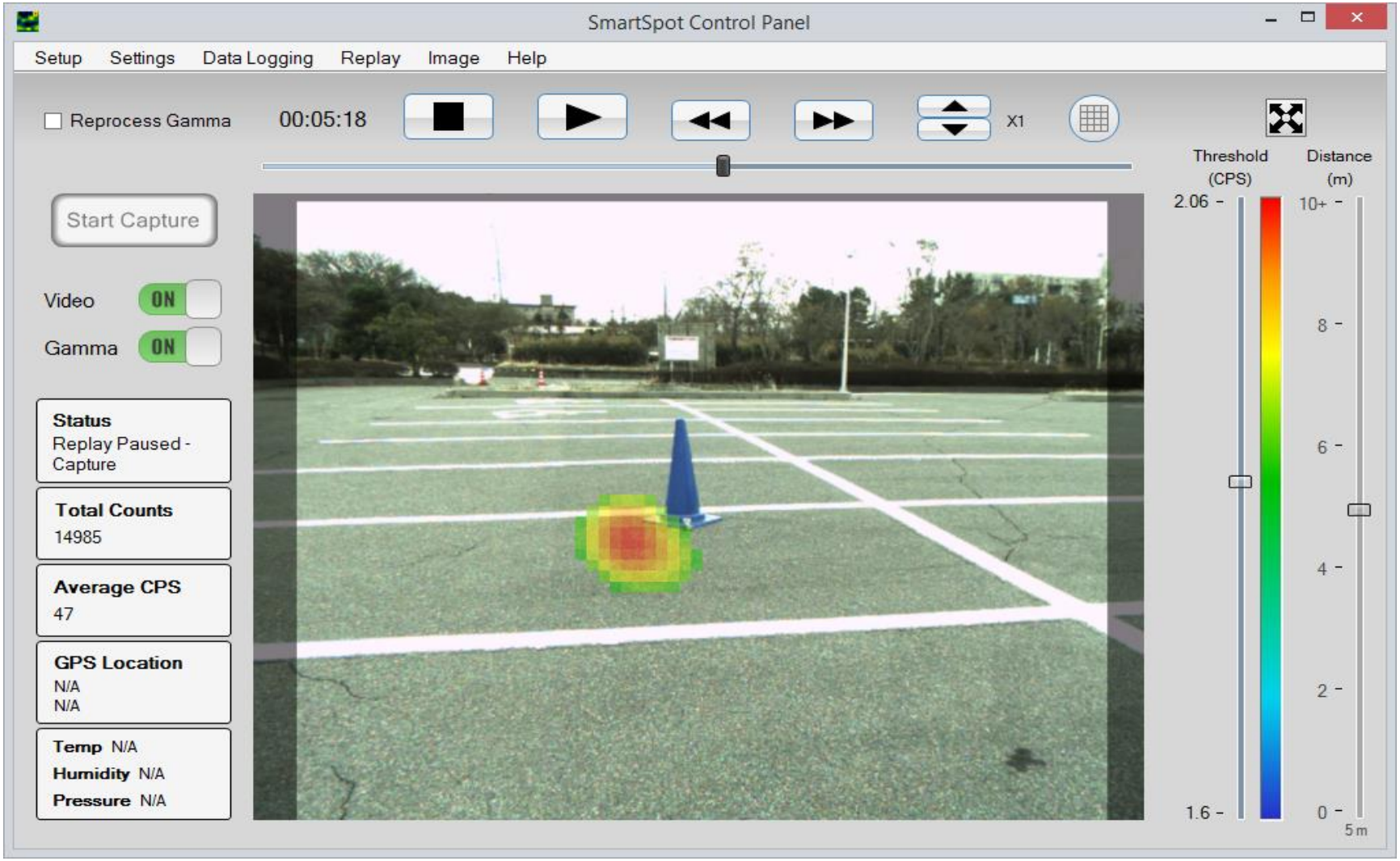



Panasonic

Comparison test in Fukushima

Parking lot after decontamination（BGD 0.5μSv/h）

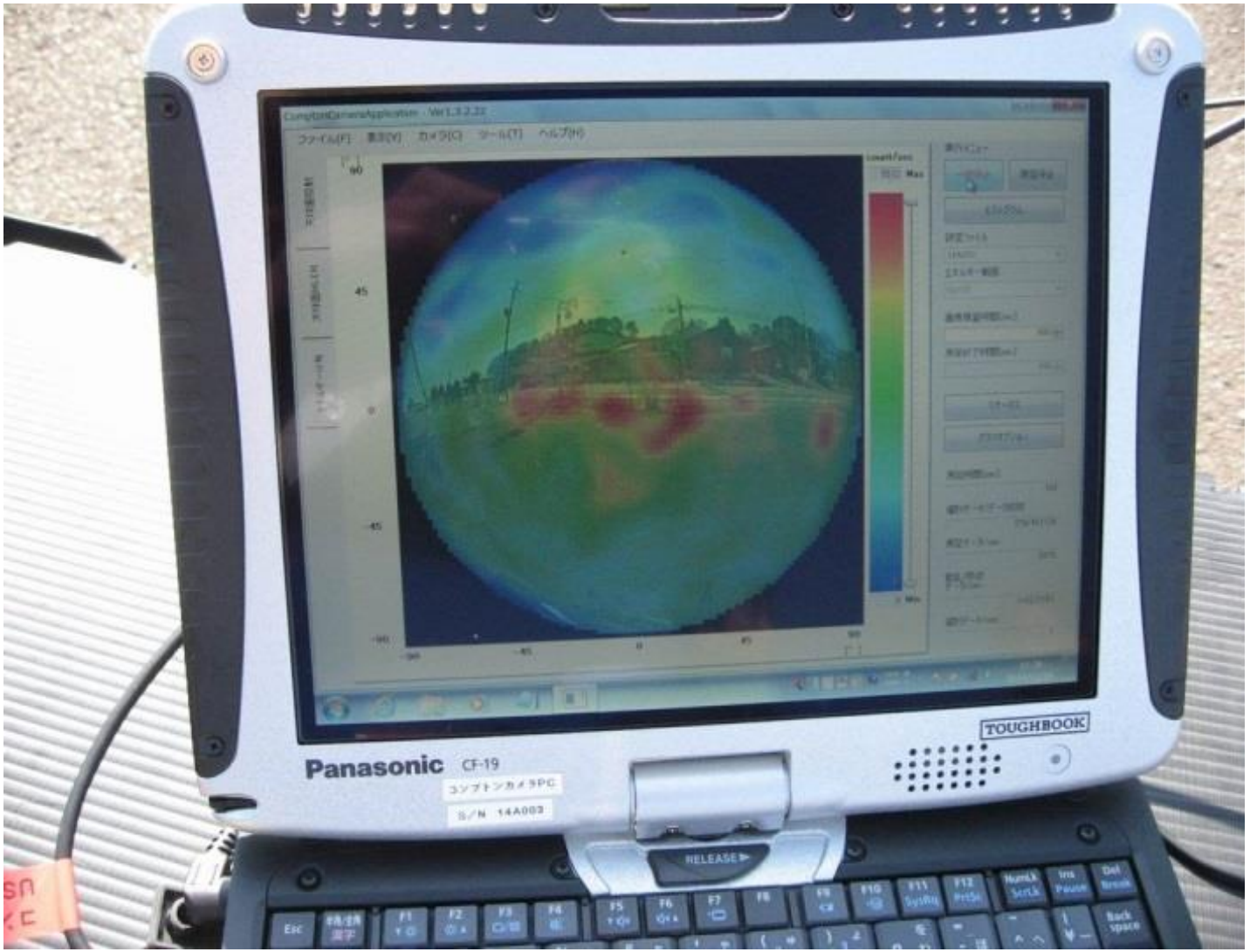
Five min capturing time at 5 m distance point source of 2MBq Cs-137




GammaDetector2
AUTO
0.00438
cps
100%
0%
2014年04月04日
13時40分
【測定中】
測定終了まで --分--秒
測定終了 (Enter)
一時停止 (Space)
画面キャプチャ (C)
やり直し
測定終了判定
自動
手動
計測表示
cps
Bq/cm²
μSv/h (参考値)
バックグラウンド補正
Report
総合
緯度: --.------ 経度: ---.------
モノクロ⇔カラー
12
count
0
200
400
600
800
1000keV
経過時間 00:10:20
全計数 616count
相対誤差 24 %
中心距離 4.70m
内部温度 23.7 ℃
内部湿度 28.3 %
HITACHI
TOUGHBOOK

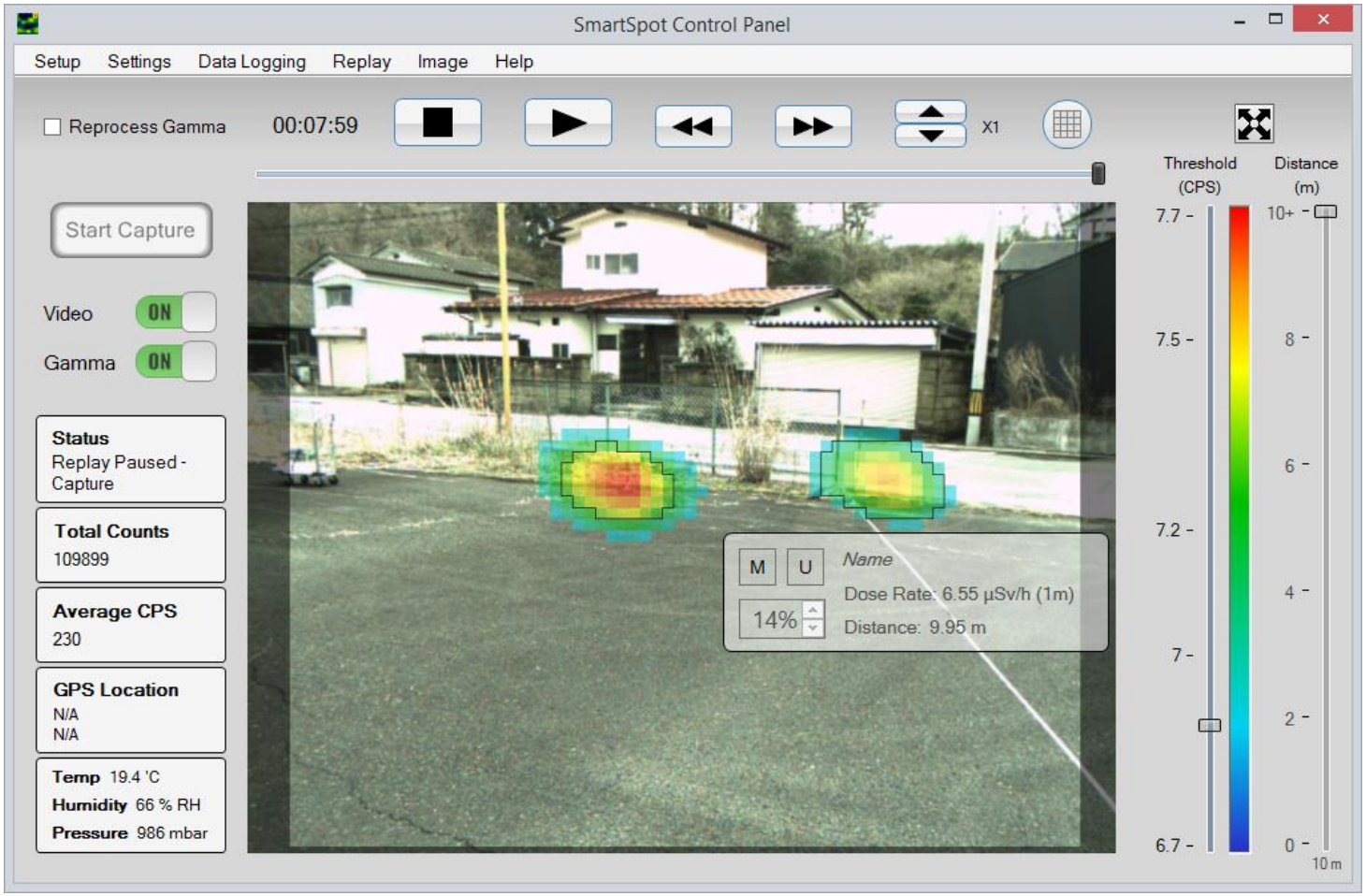
Pin hole camera for 20 min of capturing time

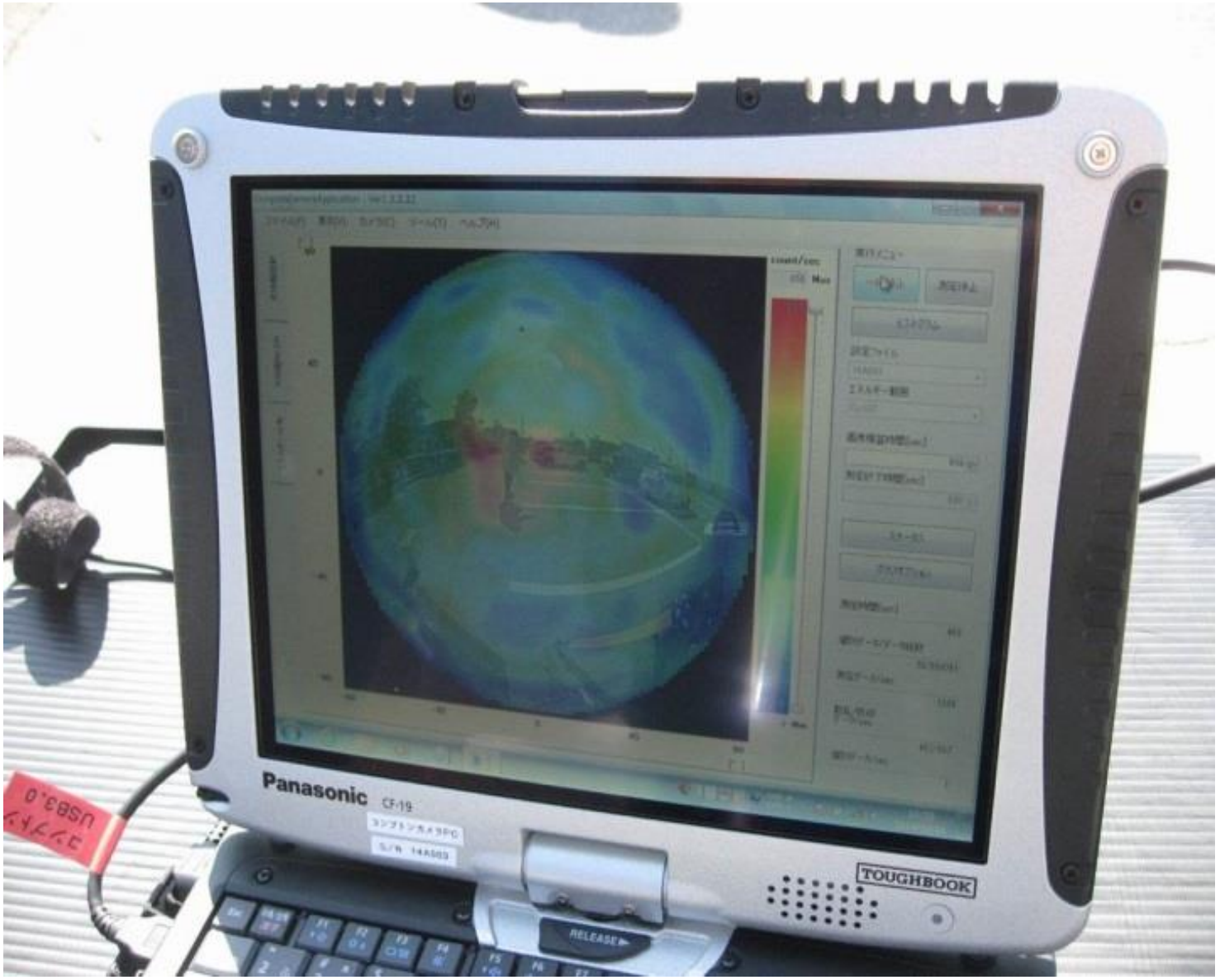
Compton camera manufactured by Hamamatsu photonics



Hot spots of Cs-137 (13 MBq) in the back ground radiation 1.5µSv/h

Distance measurement by laser gives total amount of Cs-137 in the hot spots




Panasonic
CF-19
TOUGHBOOK
RELEASE

Monitoring post at Koriyama station in Fukushima

- Aerial radiation dose at 1m height from the ground

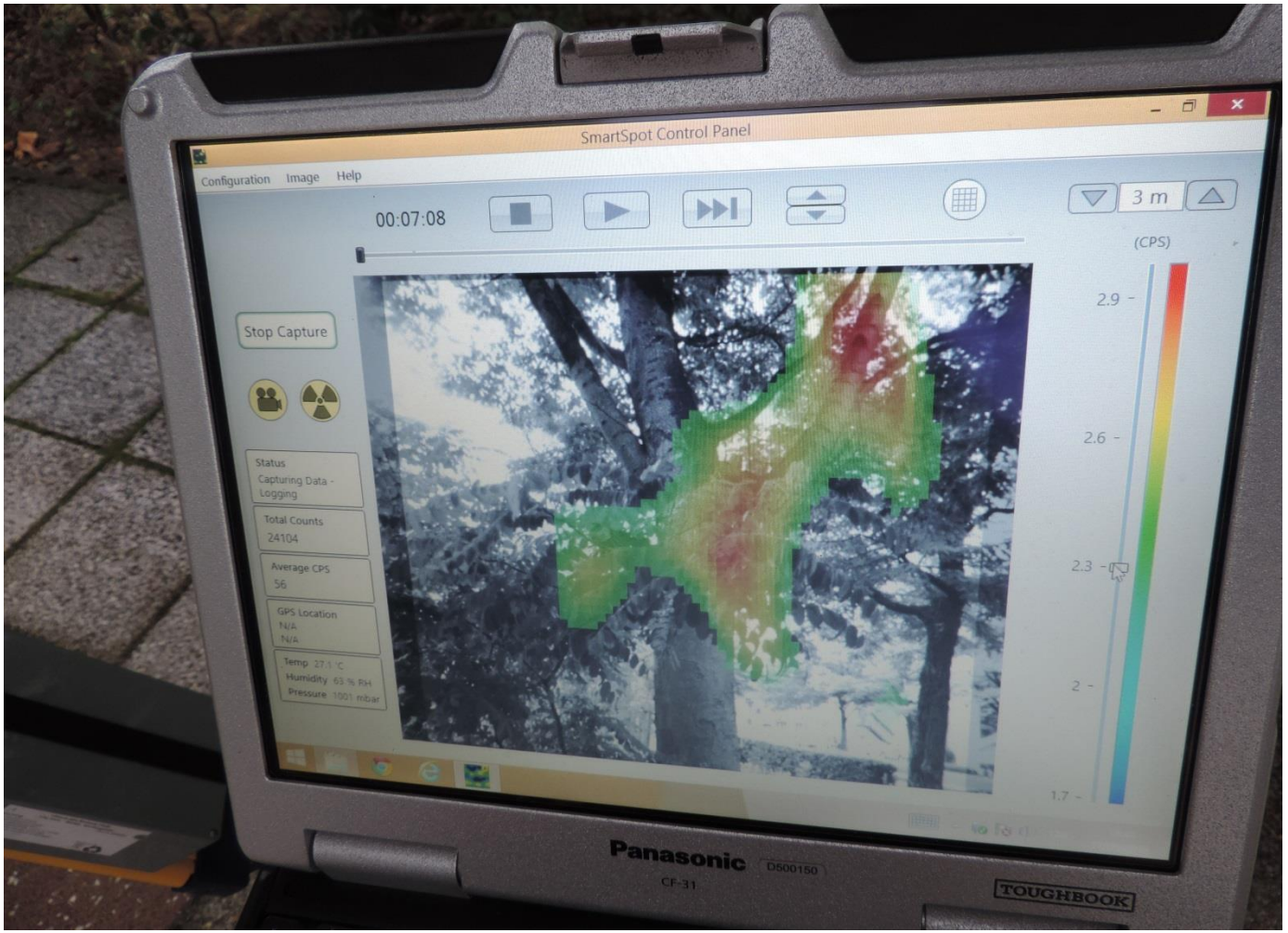
Rain carried down clays, attached with Cs-137 to the bottom of the steps

Foot of a bridge over a road way

Hot spot at the foot of the bridge

A tree nearby the over-bridge

Hot spot on trunk of a tree



Eye view of the branches

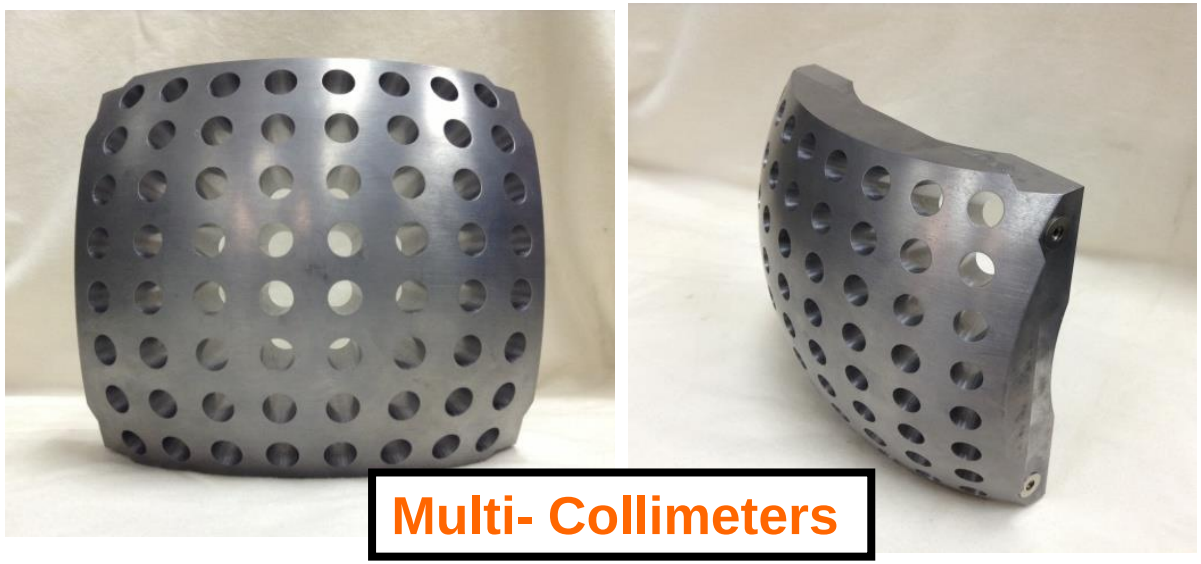

SmartSpot コントロールパネル
構成 映像 ヘルプ
00:01:05
2.4 メー
(計数毎秒)
7.5
5.6
3.8
1.9
0
測定中止
現在の実行状態
収録測定中
総計数
5395
平均計数毎秒
88
GPS位置情報
該当なし
該当なし
温度 25 °C
湿度 64 % RH
気圧 1002 mbar
Panasonic
D500150
CF-31
TOUGHBOOK

Request from potential customers of coded aperture type camera

1, Weight; 10kg (to the half)
2, Capturing time; 2 min (to the half)
3, Price; 10 million yen (to the half)
4, Made in Japan if available (from UK)

Multiple Collimaters

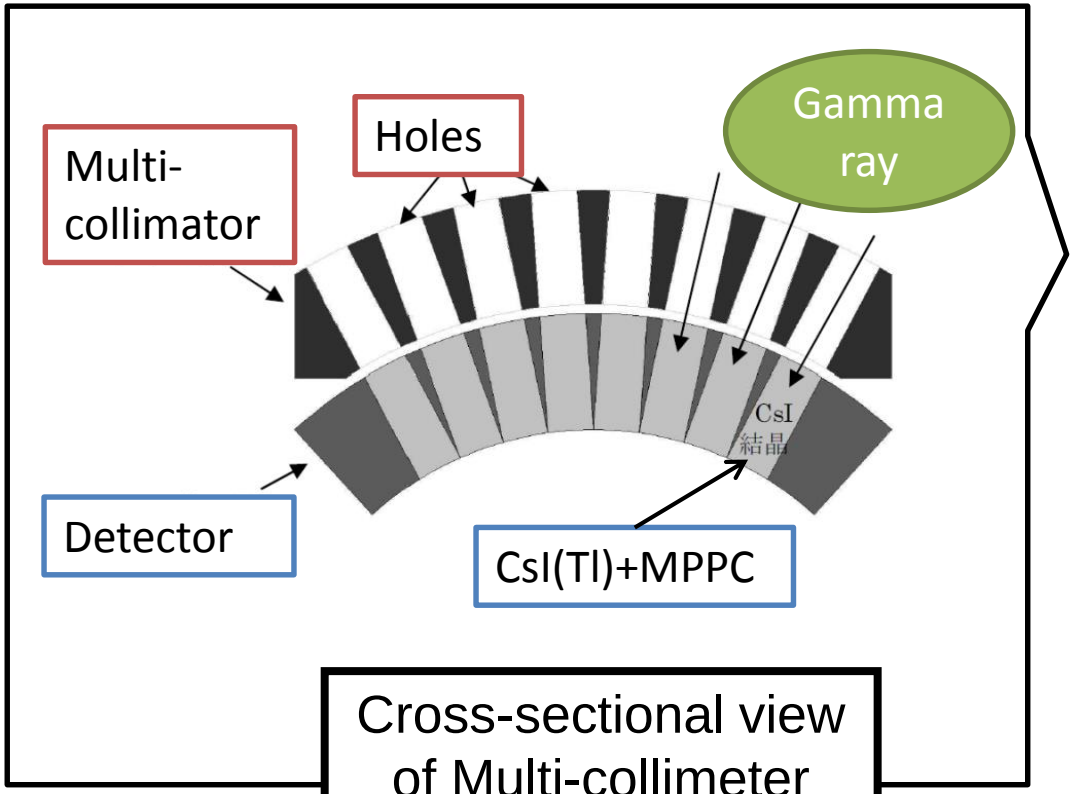
- **A lead shielding body which has 64 holls on the spherical shell**
- **64 holls radiate from the center of sphere**
  →Only photons that enter from unique directions permit through in detectors
- **Holls are arrayed 8×8**
  → enabling wide field of view
  (length:56.7°, breadth:67.2°)



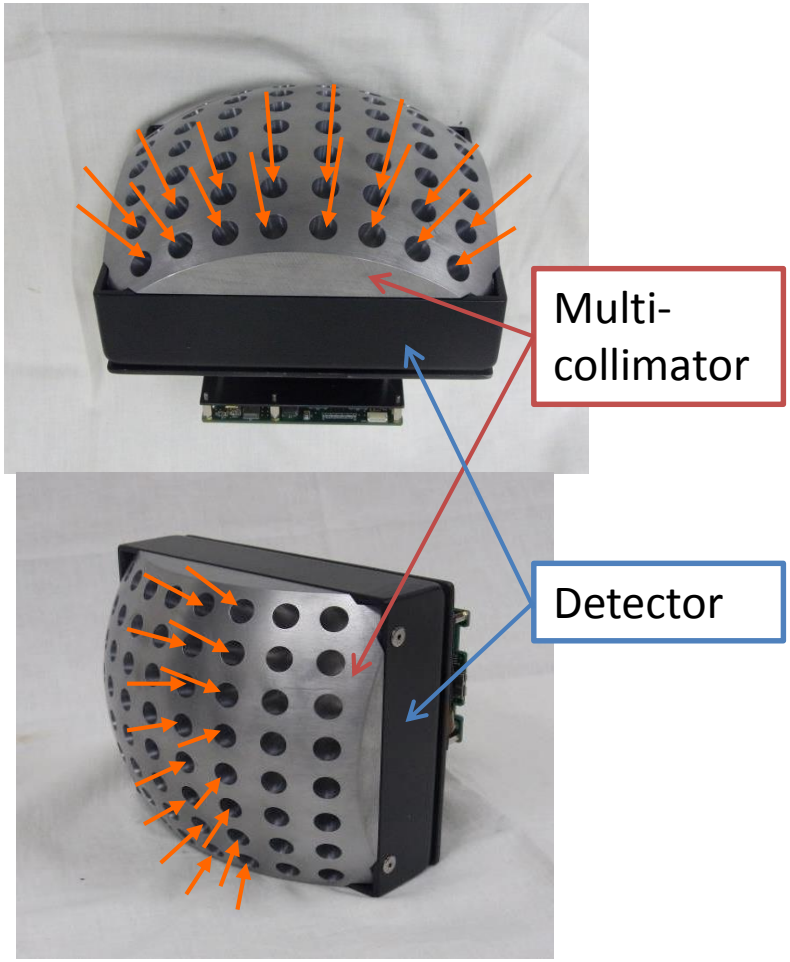
Multi- Collimeters

Multiple collimator type device

Pair of hole and CsI(Tl) detects the direction of gamma ray coming in from the field of view



Cross-sectional view of Multi-collimeter and detector devise



■ 64 holes and CsI(Tl) devices are paired

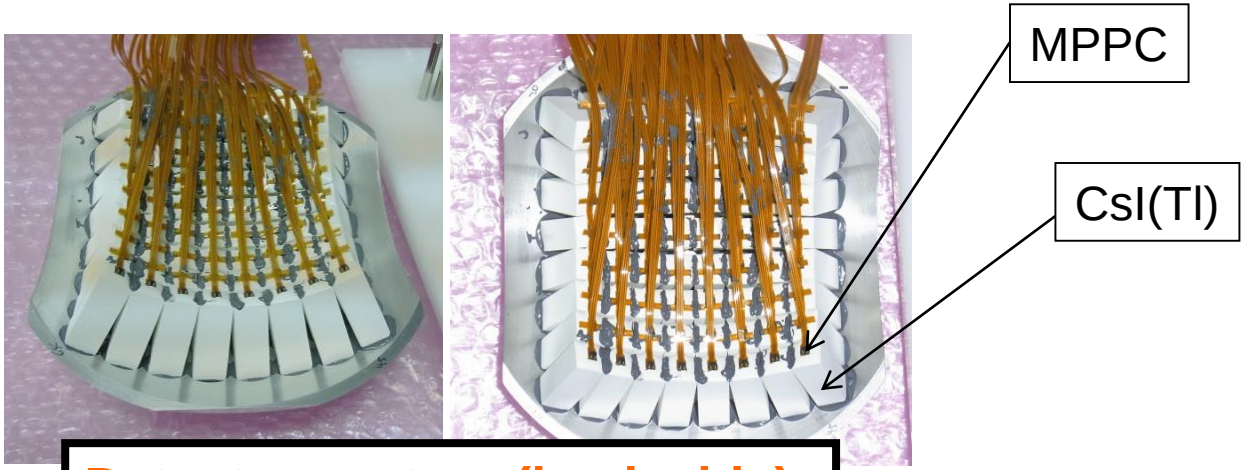
・This detector system has 64 CsI(Tl) devices arrayed in 8×8

→ Each CsI(Tl) scintillator detects photons which passed through each multi-collimator hole

→ Count intensity of each CsI(Tl) scintillator relates number of photons which reached through each multi-collmator hole

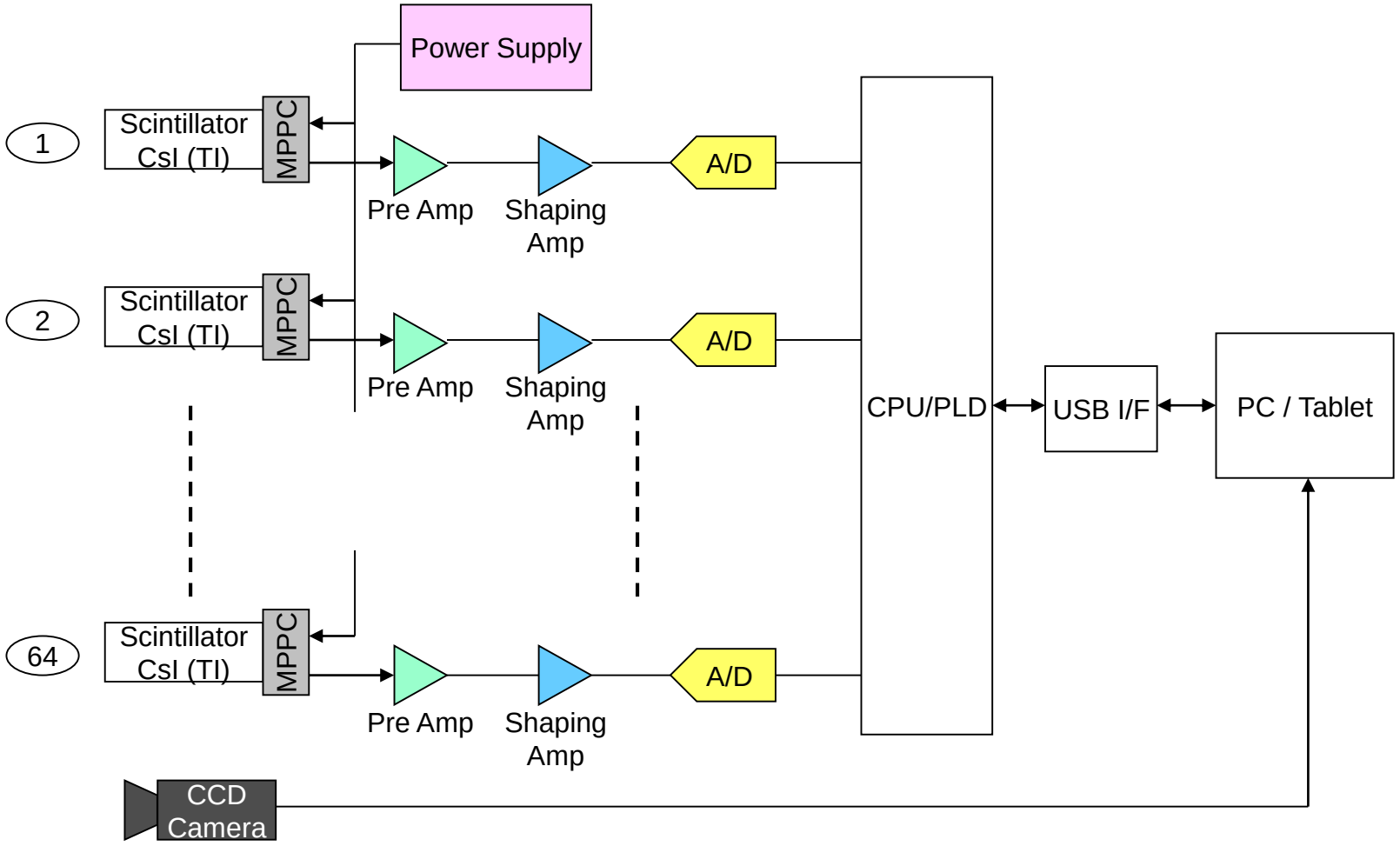
→This system can show distribution of gamma ray in field of view

・64 CsI(Tl) devises placed radially from the center of sphere as well as multi-collimator holes



Detector system (back side)

Block diagram of multi-collimator type gamma camera



Multiple collimator camera

Specification and performance

1 Visualized method: Multi-collimator type

2 Targeted nuclides: Cs-134/ Cs-137

3 Energy range: 30-1500[keV]

4 Capturing time: 1 min (In case net air radiation dose rate from Cs-137 be is 1[μSv/h])

5 Viewing angle: 60°

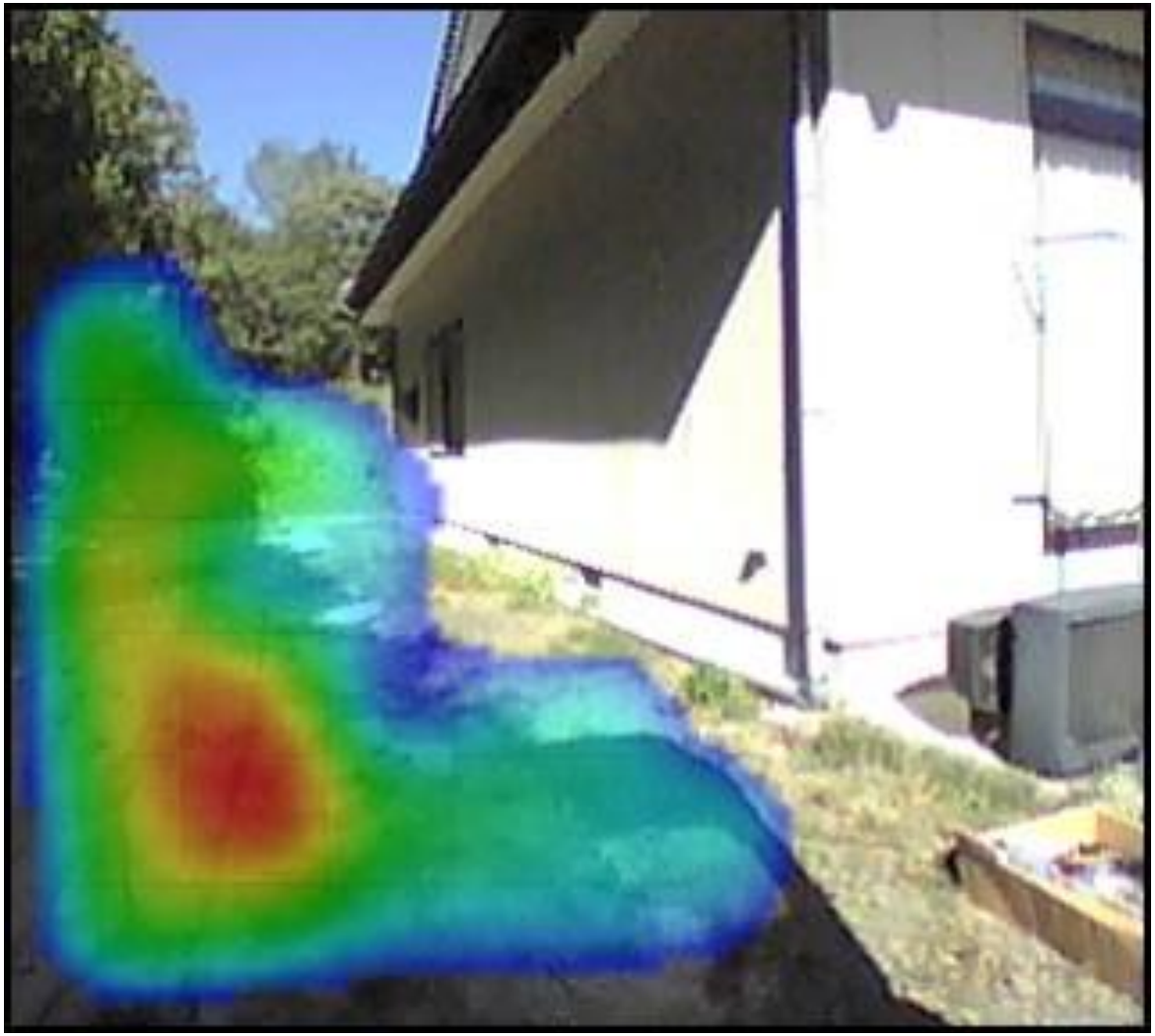
6 Spatial resolution ：3°

Specification and performance(continued)

7. Detector
   1) Scintillator
      ①Material: CsI(Tl)
      ②Size: 10mm ×10mm ×25mm
      ③Number of crystals: 64
   2) MPPC (Multi Pixel Photo Counter)
      ①Number of devices: 64
8. Optical camera: Flat CCD camera
9. External output terminal: USB 3.0
10. Power supply: Internal battery (8h), External battery (2.5h×2set)
11. Body size: 175mm(W) ×175mm(D) ×205mm(H)
12. Body weight: 10 kg
13. Operating machine (PC): Windows Pro Tough book 10.1inch

A house after normal decontamination in Iidate village

Hot spot at the ditch of a house



Cs-137 mapping from the sky is proceeding now

Drone (mini surveyer)

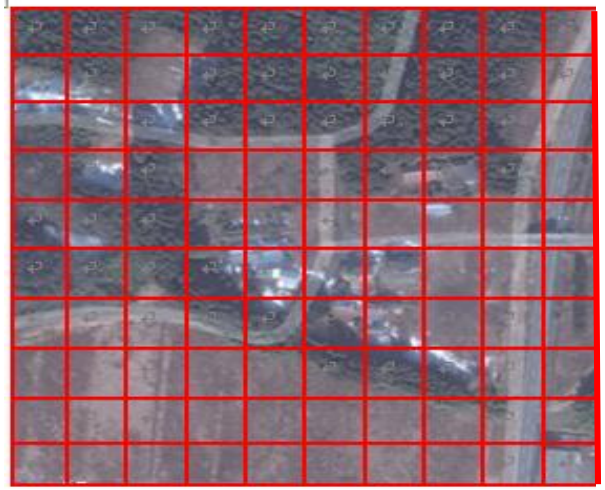
Altitude
10m

Measurement unit
- Gamma ray detector
- CCD camera
- GPS
- Communication module

2.4GHz/5GHz
Radio

Display unit
- Optical images
- Cs-137 distribution
- Location information
- Flight route

Measurement area
12m × 12m
100m^2



Surveying perfomance:
100m × 100m/day

Drone landed off the ground in success

Drone hovering at 10 m high for the gamma camera to capture Cs-137 mapping image on the ground

Drone suddenly dropped and crashed to the ground breaking it’s wings and the gamma camera

Heath effect of low level radiation

- Total exposure of gamma radiation to the body of the author: 134mSv
- Spellbound thoughts of Fukushima people for additional 1 mSv of annual exposure
- Radiation literacy and mental care
- Supporting healthy daily life

Malignant tumor

No one can tell whether or not the cause of any tumor is attributed to the radiation that the patient was exposed to in the past;

Leukemia

Lymphoma

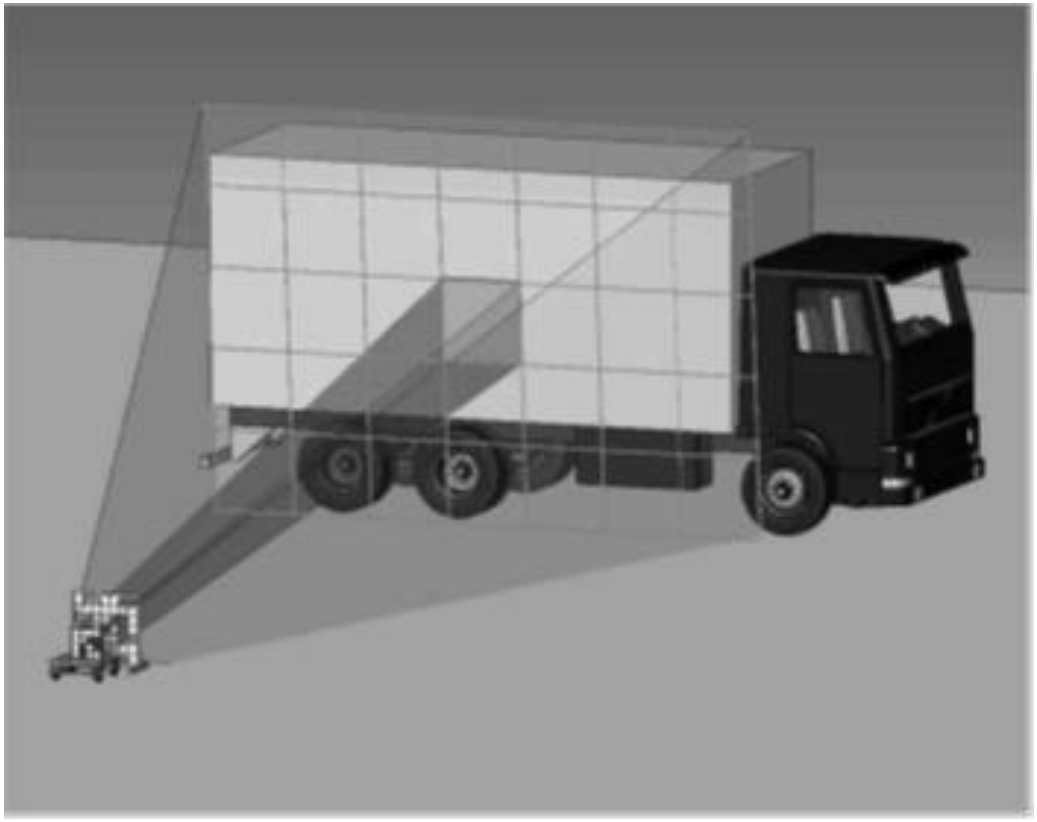
Multiple Myeloma

Gamma camera for gate monitoring to detect high radioactive wastes loaded on a truck

●Detector unit
40mm × 40mm × 25mm CsI(Tl) devices are arrayed 6 × 8 using 48.

●This camera can detect and locate high radioactive waste bags.

●Survey time: 3 min per truck when LLD is 100[Bq/kg]

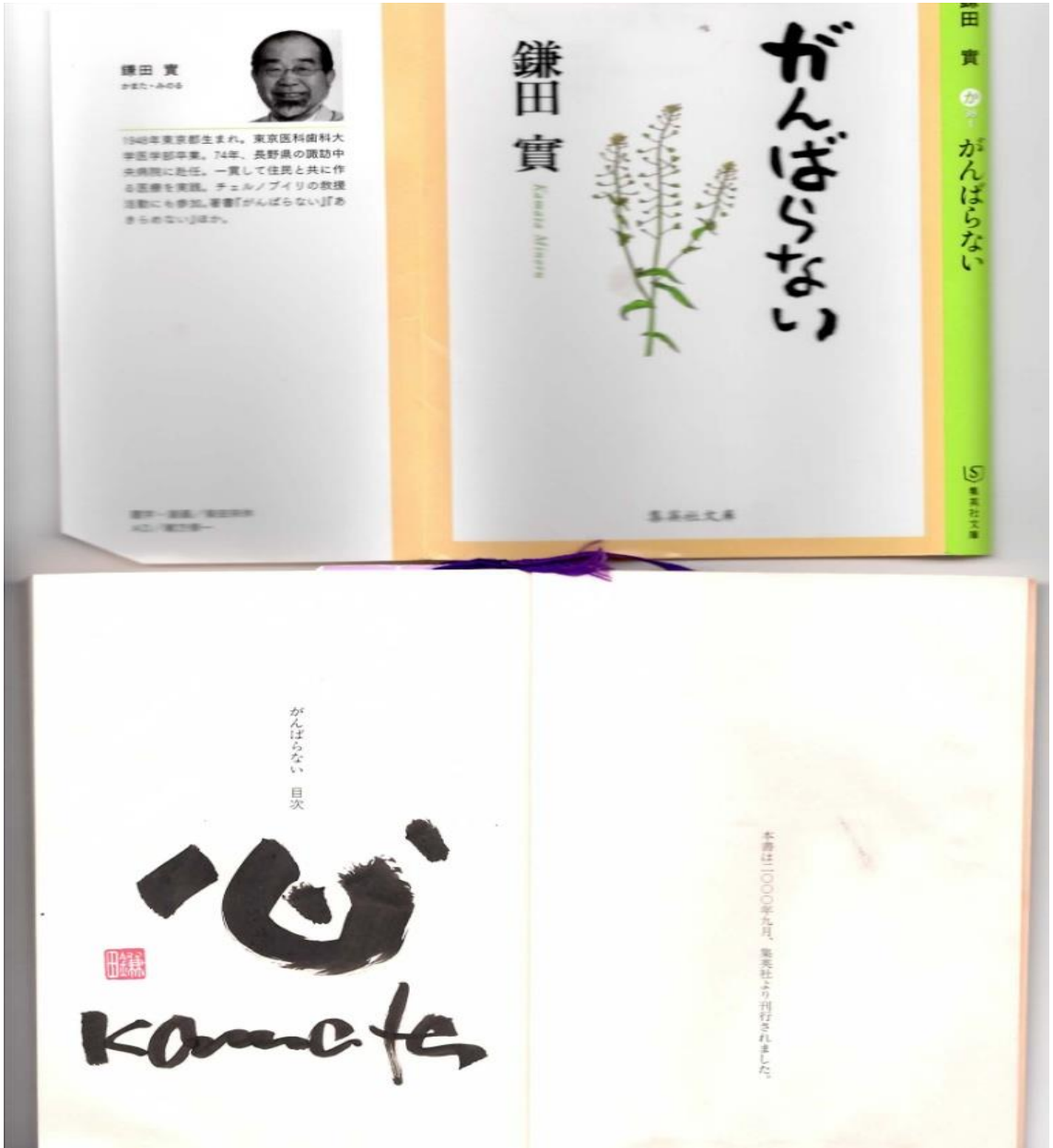


The work to be continued

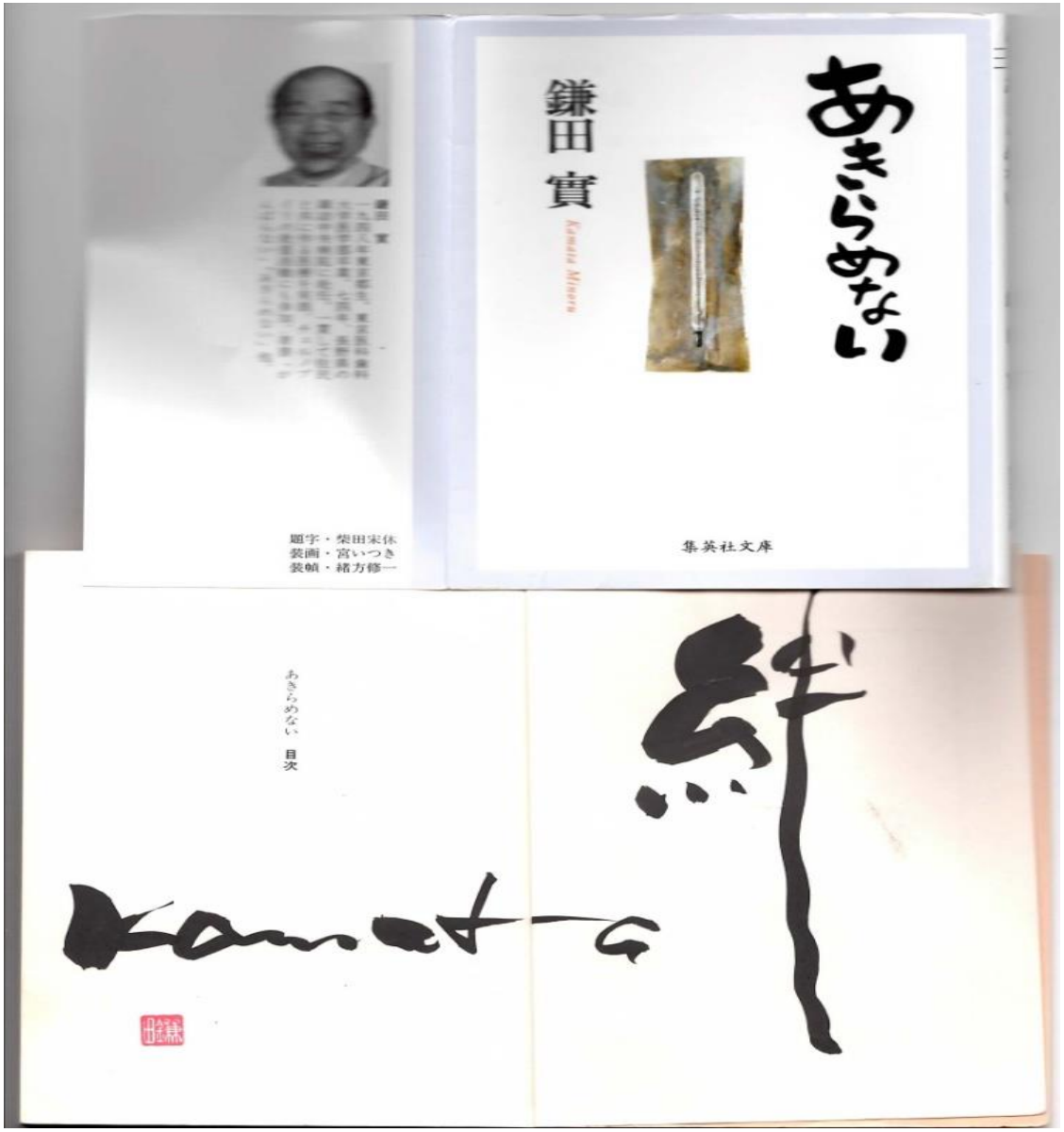
- Cs 137 mapping off site of 1F for supporting decontamination
- Cs 137 mapping on site of 1F facility and other old nuclear power plants for decommissioning
- Counter measure against radioisotope terror attack
- NORM detection in Petro plants and tank
- Button touch to the next generations
- The experience of Fukushima recovery to be shared with other countries
- Distribution mapping of Cs 137 caused by the Chernobyl accident

Around the world cruise and natural radiation measurement in 2000

Minoru Kamata “Do not hold out”

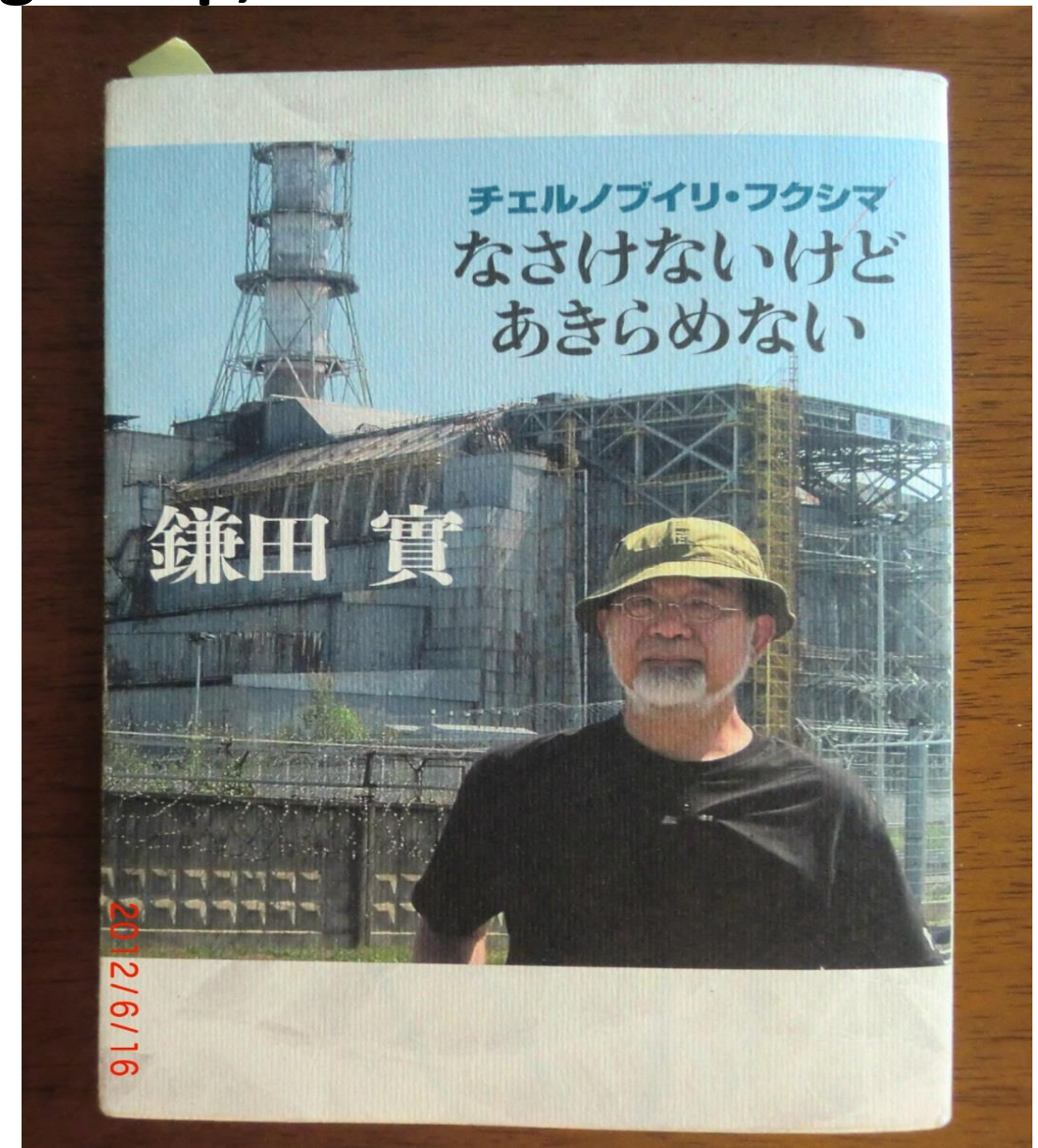


Minoru Kamata “Do not give up”



We met together during the cruise

Minoru Kamata “ Chernobyl and Fukushima: Do not give up, however it is sad indeed”



Ms. Svetlana Alexievich, Nobel Laureates for literature, 2015 and M.D. Minoru Kamata