Muon Radiography with the Plastic Scintillation Counter

(The imaging of the large Structure)

KEK, Univ. Tsukuba, Tokyo Met. Univ., Univ. of Tokyo, TEPCO

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@ Tsukuba University

2016 - 3 - 2

Content

ミュオン透過法による原子炉調査

KEK，筑波大、首都大学、東京大学、東京電力

2016 - 03 - 2

1 : Introductory remarks

Research Proposal to KEK Director General

Inspection of Nuclear Fuel Status of Fukushima-Daiichi Nuclear Reactors by Near-Horizontal Cosmic-Ray Muon Radiography

K. Nagamine

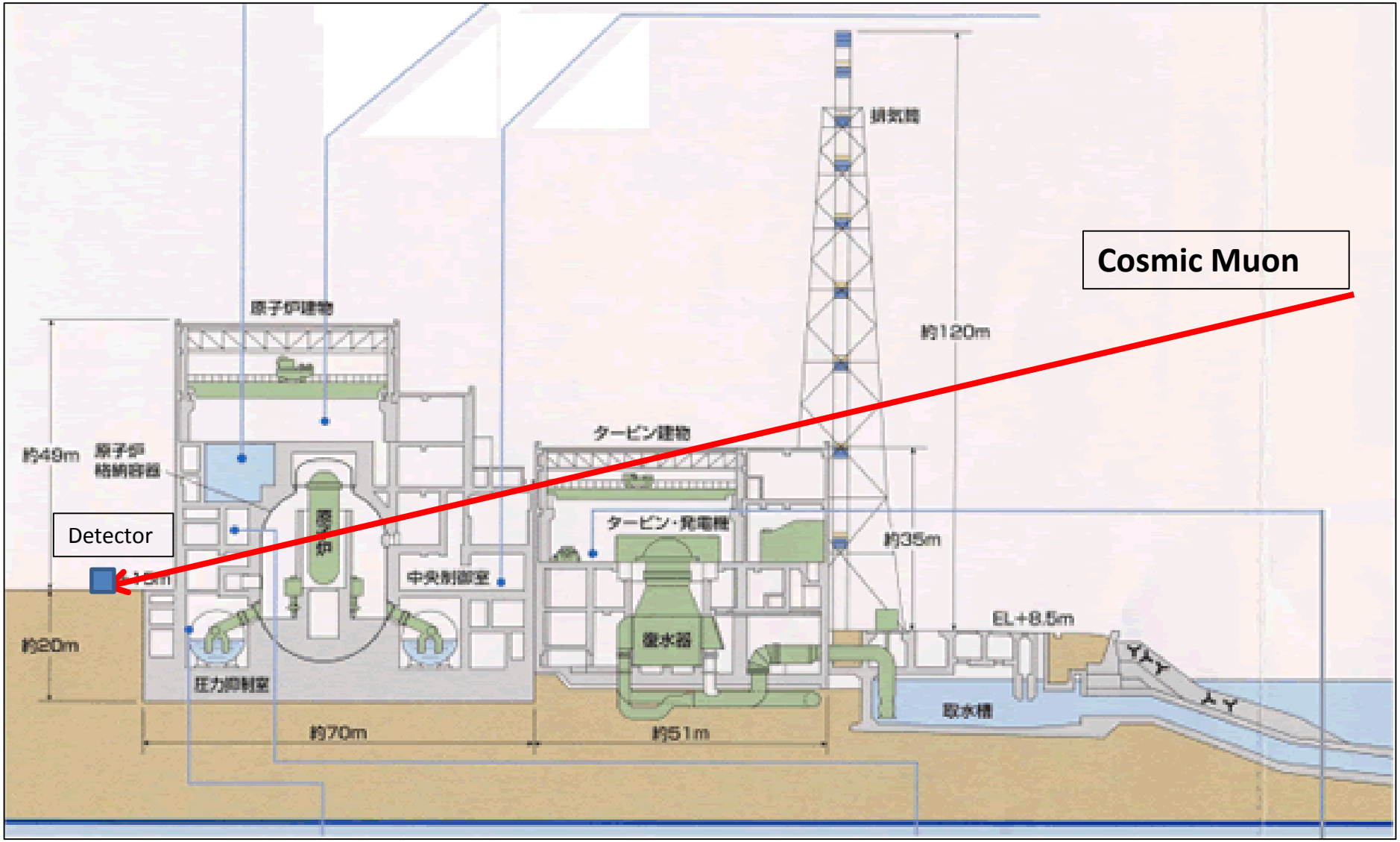
Muon Science Laboratory, IMSS, KEK

(April 7, 2011)

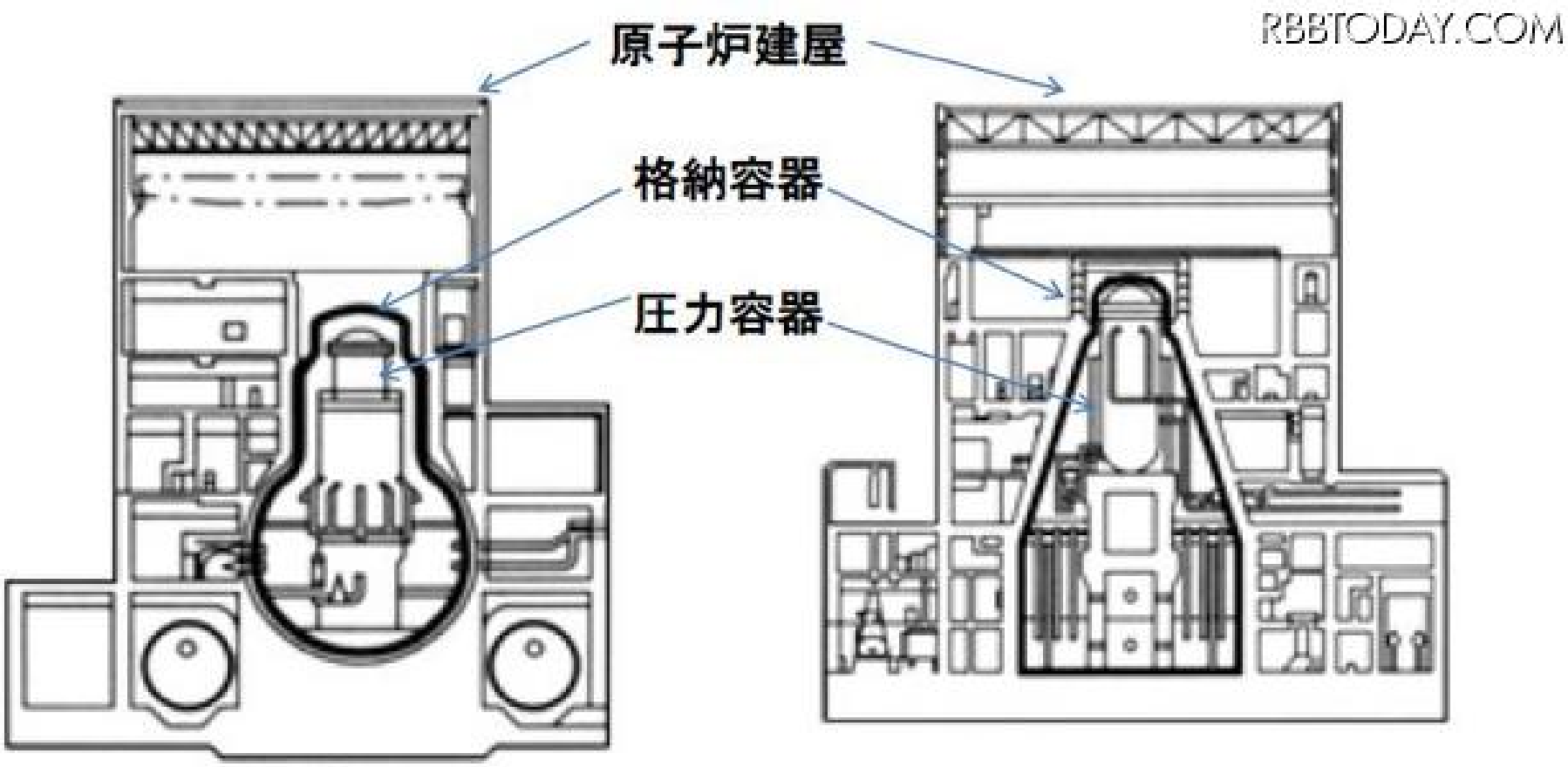
osmic-ray muon radiogra g the
pre bly in the damaged nucl hima
Dai earthquake-Tsunami di . By
em sition-sensitive detectors lastic
sci l resolution of ±1.5 m, t l rod
ass atial resolution of ±5 cm n the
det ust outside of reactor con . The
res l help to determine the e ision

K. Nagamine proposed to study the damaged reactor by the Cosmic Muons (CMR) to A. Suzuki, then DG of KEK, and he supported his proposal and organized a study team at KEK in March 2011.

Schematic View of the Nuclear Reactor at the FD



Two Types of the Nuclear Reactor at the FD



GE-MKI

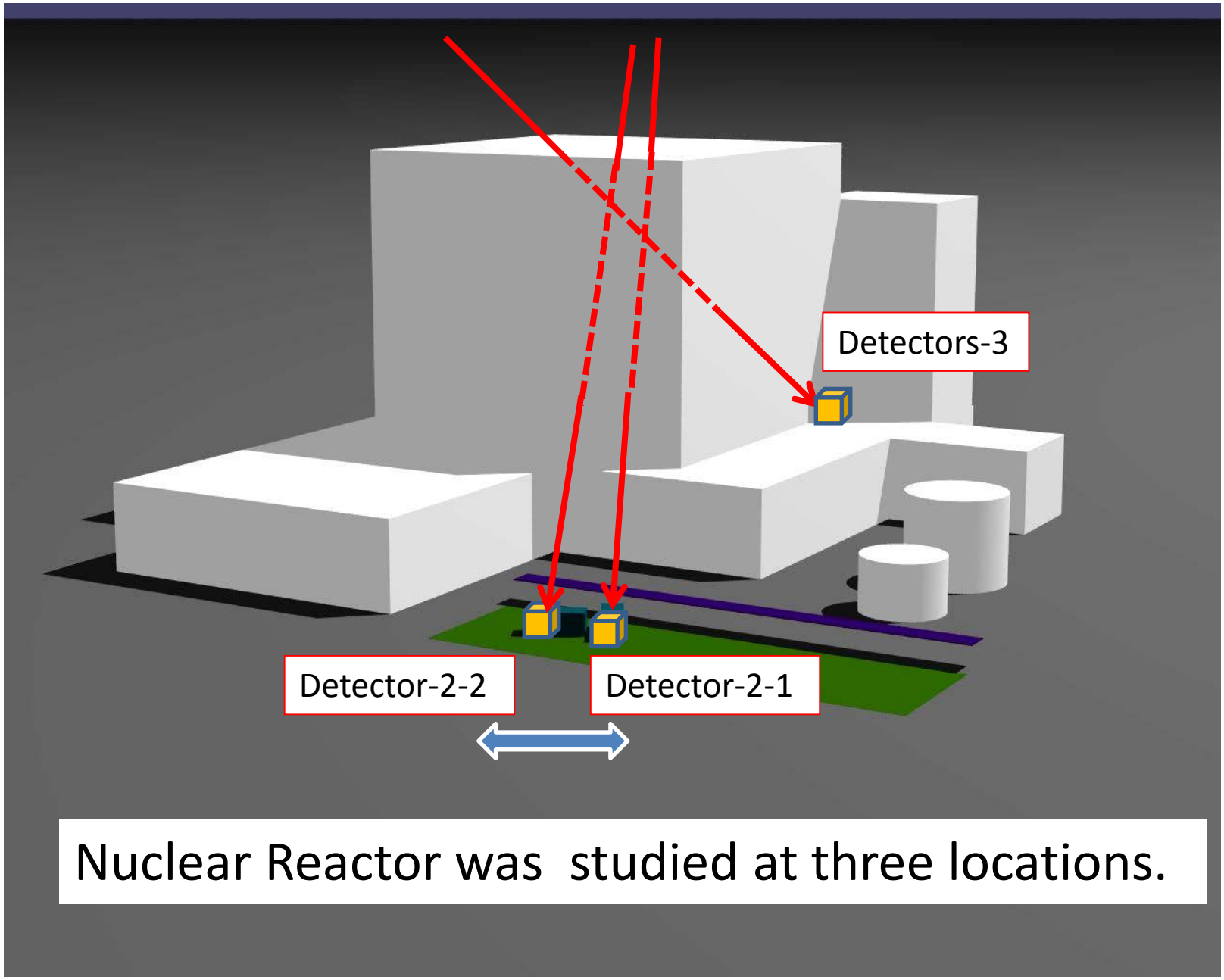
第1～5号機

GE-MKII

第6号機

2: Test Experiment at the JAPC @Tokai, Ibaraki

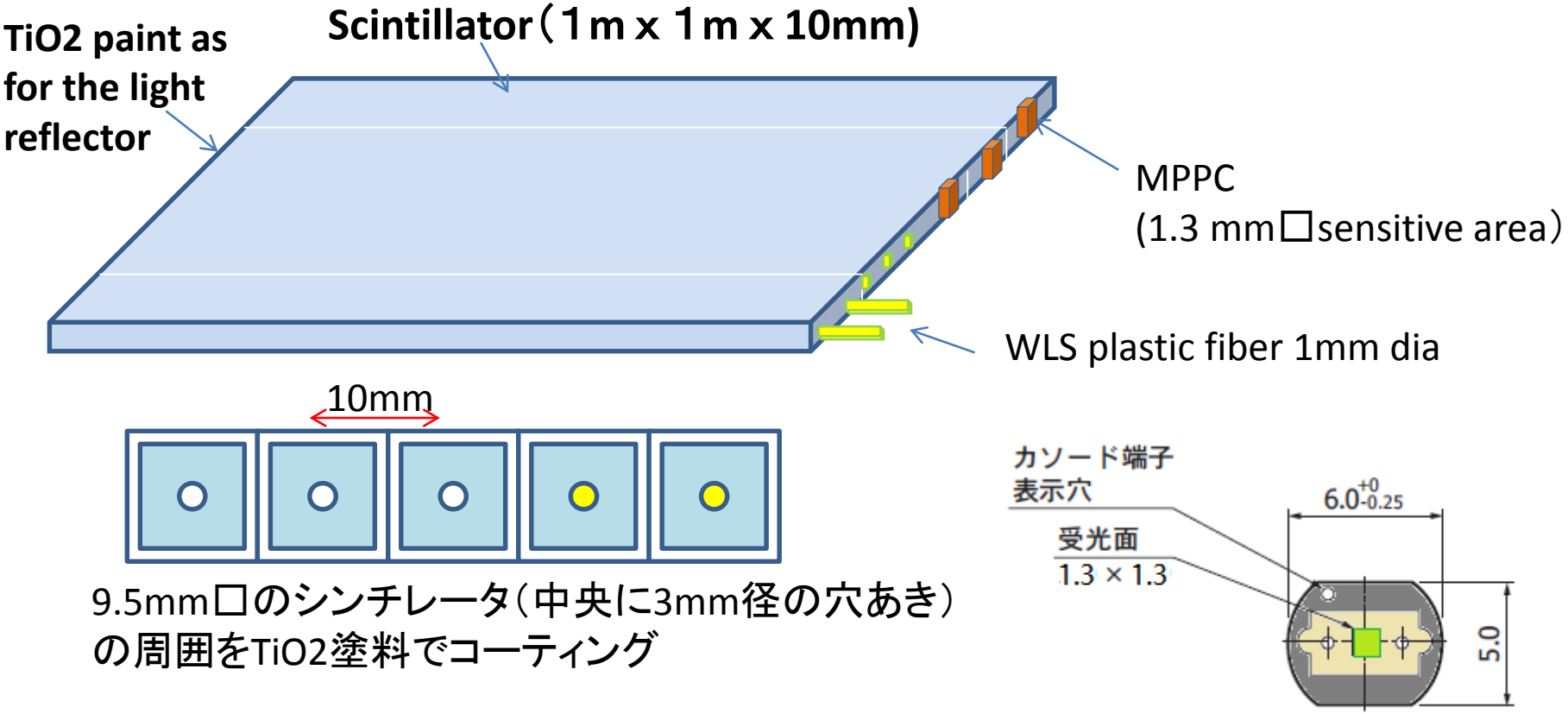
- Reactor : GE MKII type
- Experiment : from mid 2011 to the end of 2013

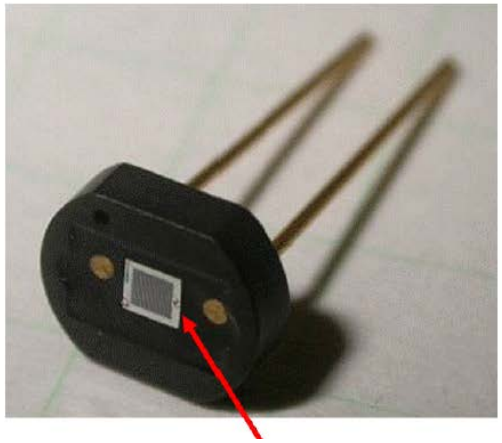


Nuclear Reactor was studied at three locations.

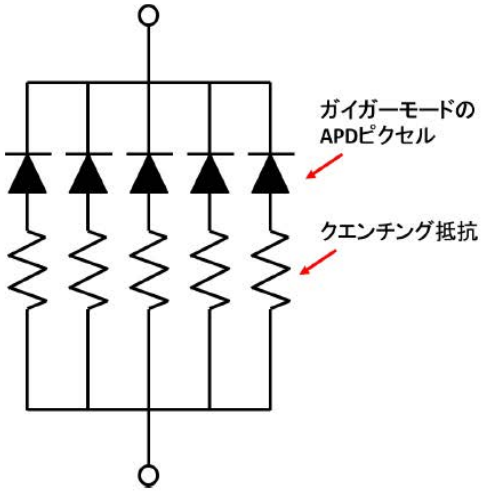
Cosmic Muon Detector

Plastic Scintillator Bar
+ Wave length Shifter Bar



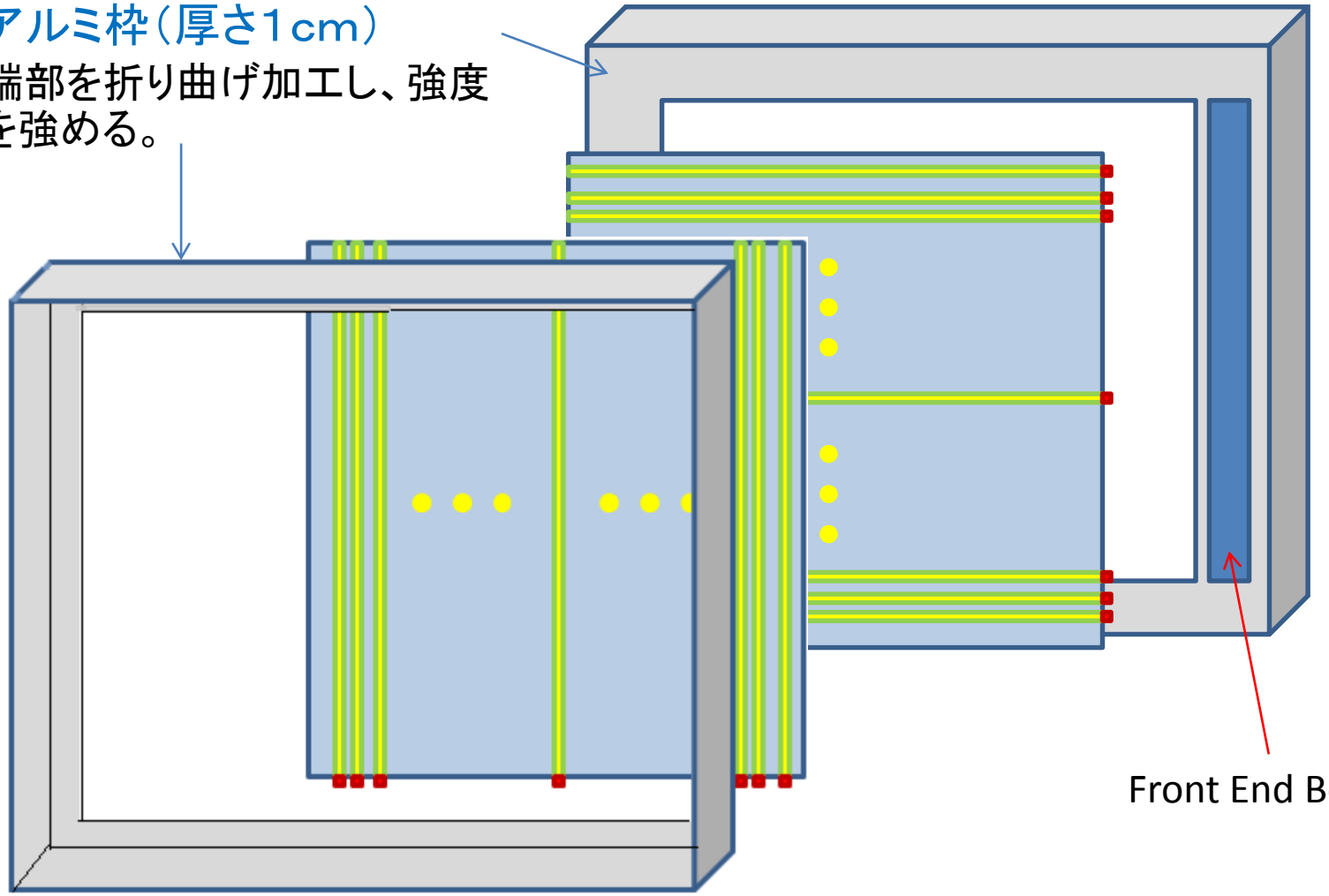


MPPC



X-Y Detector Unit

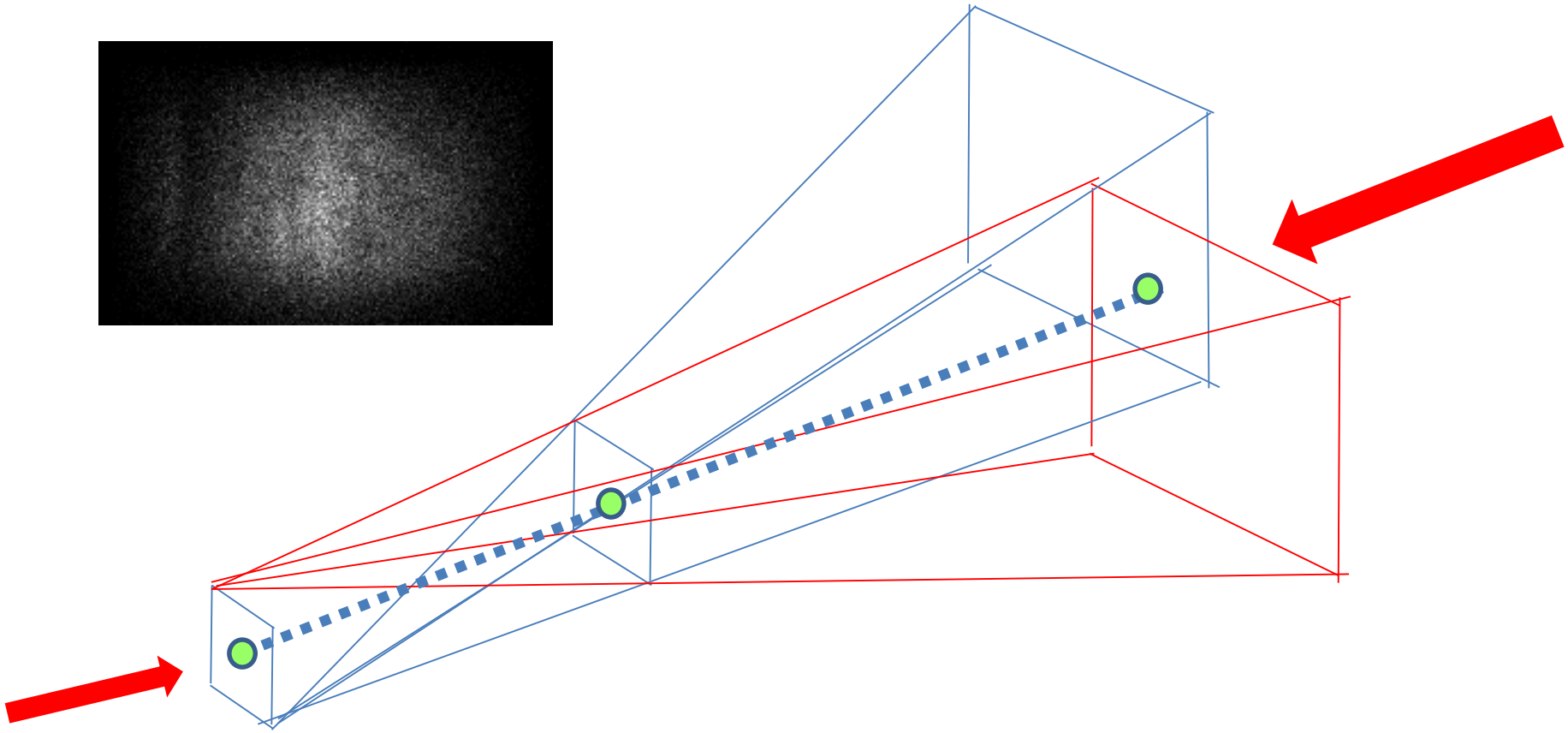
アルミ枠（厚さ1cm）
端部を折り曲げ加工し、強度を強める。

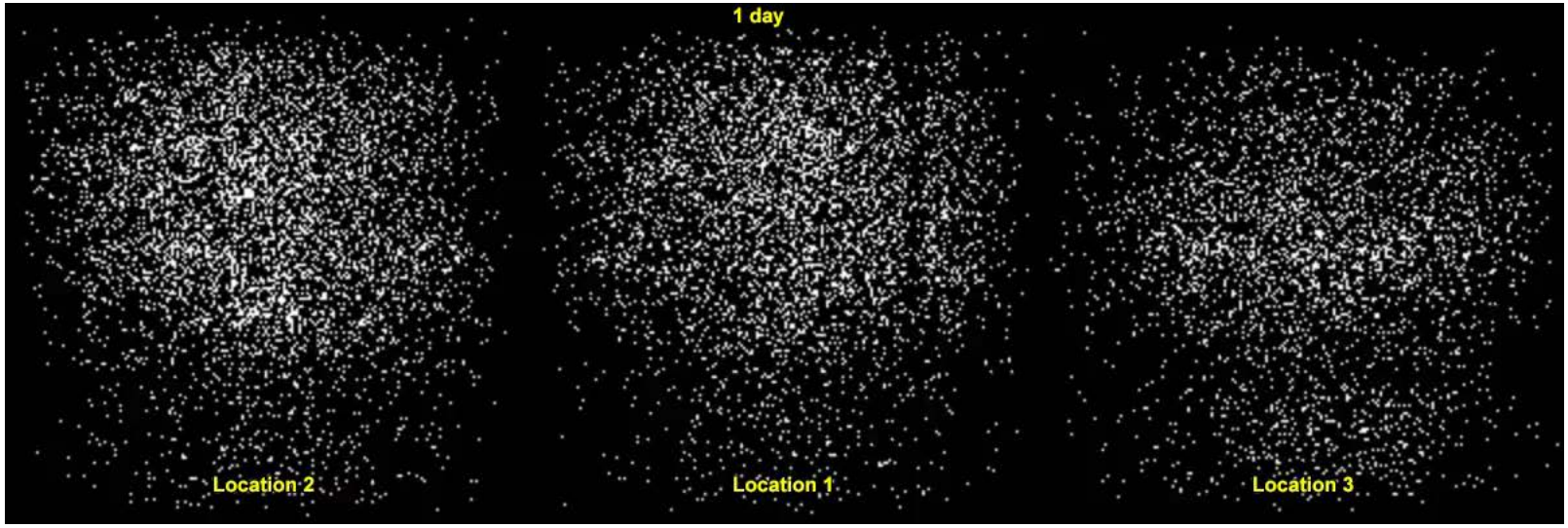


シンチレータ前後面に反射シート（白色PET）
さらに外側から遮光用黒シート

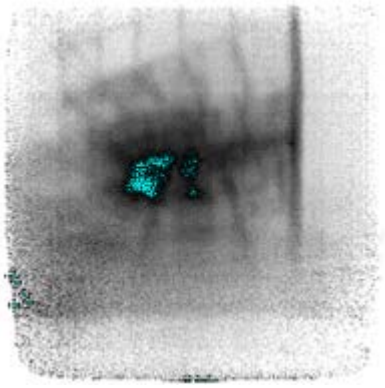
Images formed from the two Hodoscopes

“Bright Center Part”
It is like an image of the pin-hole camera.

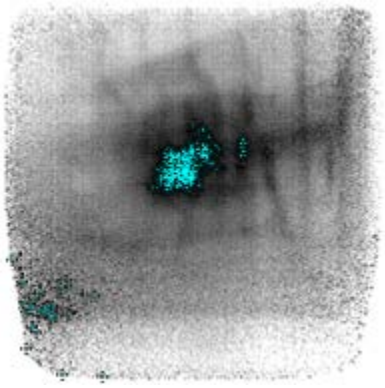



1 day
Location 2
Location 1
Location 3

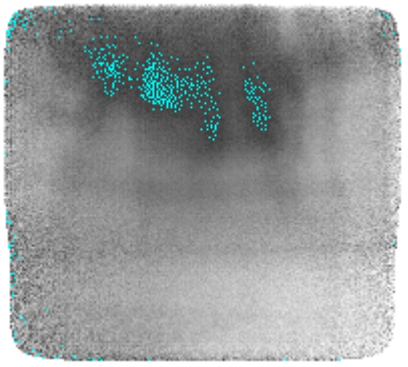
Observed Spots of Heavy Absorption



Point 1



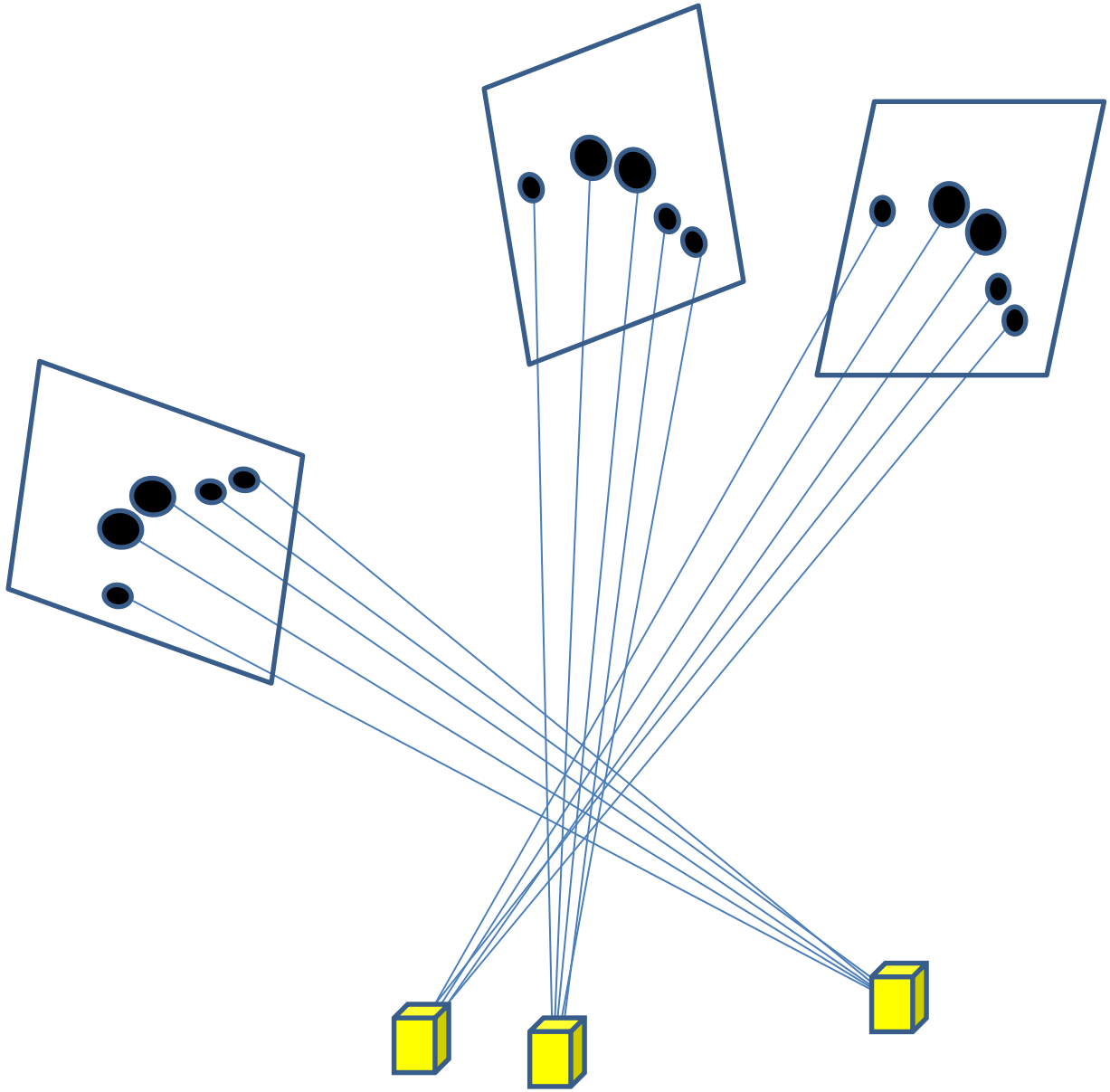
Point 2

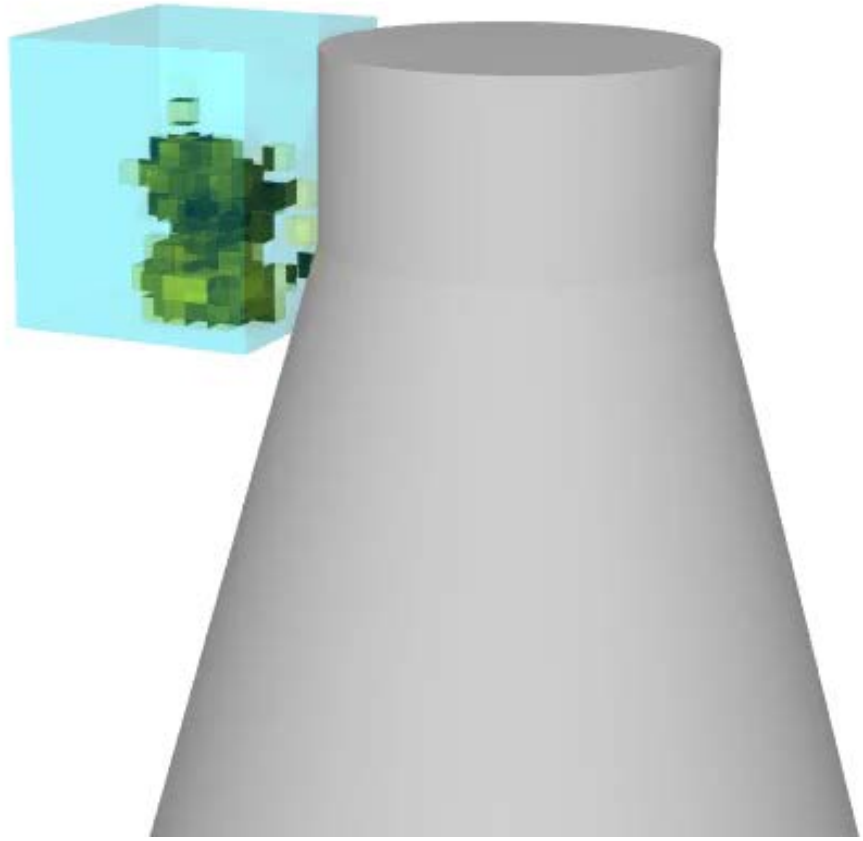


Point 3

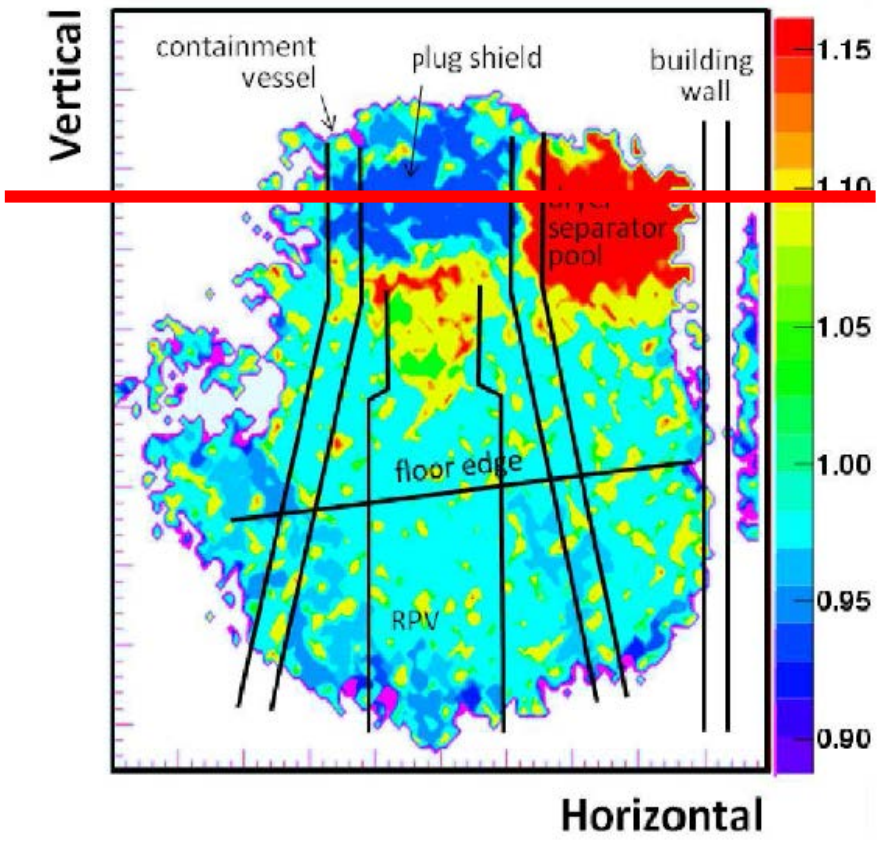
Combined Analysis

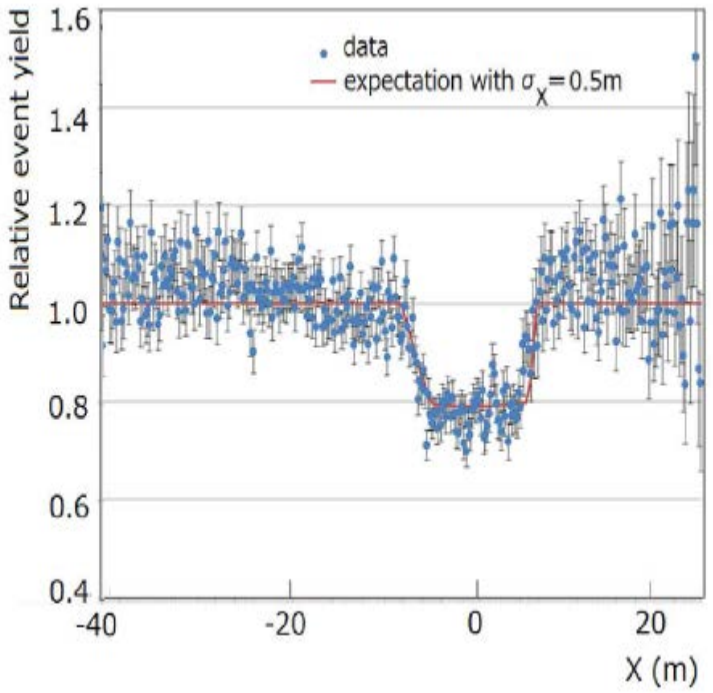
Spots of Heavy Absorption are in the Storage Pool of the Nuclear Fuel.





Accuracy of Position Measurement





3: Study at the Fukushima Daiichi

- 3-1: Goal of the Study
- 3-2: Protection against the radiation
- 3-3: Detection System
- 3-4: Present Status of the Study of the reactor
- 3-5: Related Works

Nuclear Power Plant of the Fukushima Daiichi

3-1：Goals of the Study

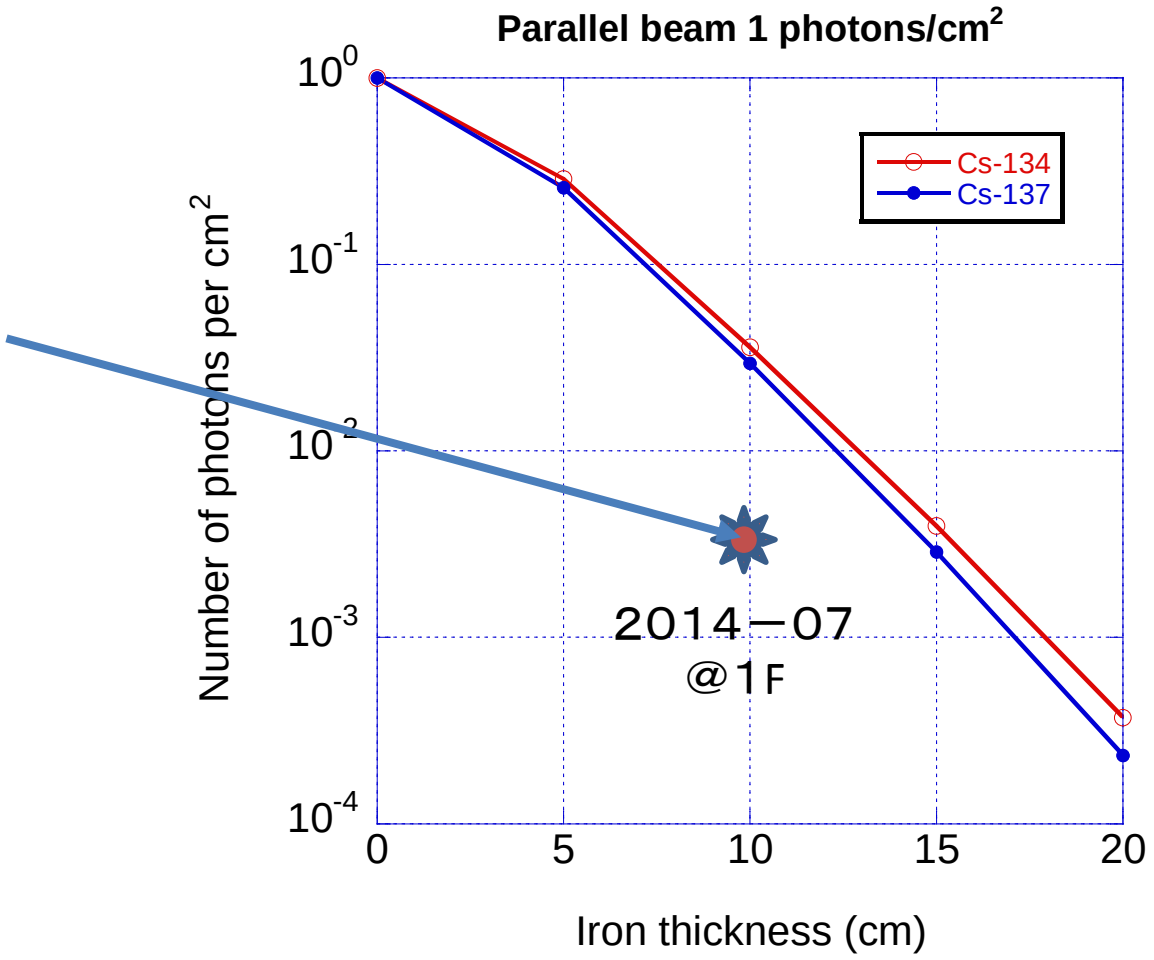
A） To know if the heavy of object such as the Nuclear Fuel > 1m could be identified and located

B） To know if the heavy of object such as the Nuclear Fuel > 1m remains in the PV

C） To know if the the Nuclear Fuel remains in the Storage Pool

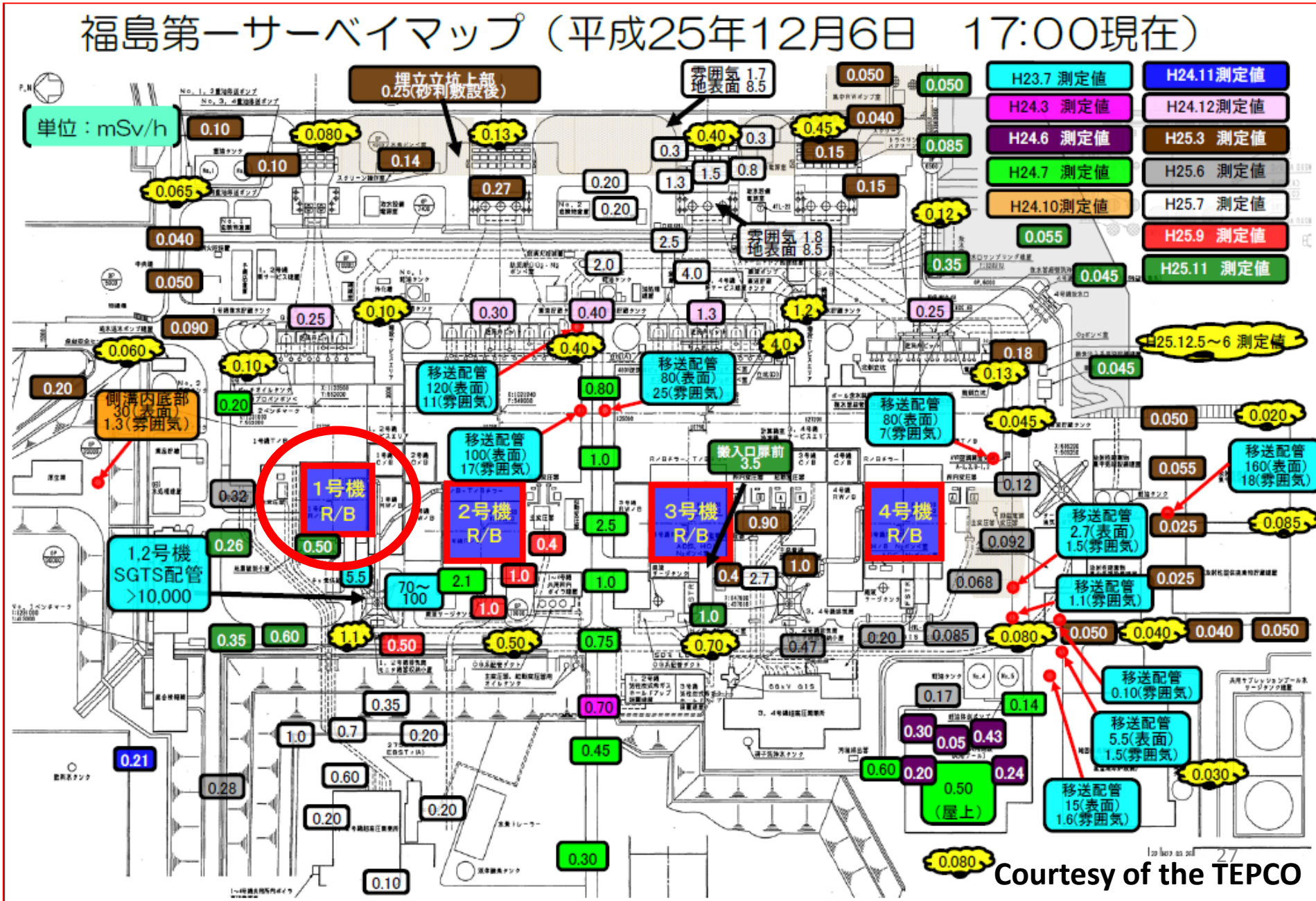
3-2：Protection of the Detector against the environmental radiation of O(0.5mSV <)

Measurement at Fukushima

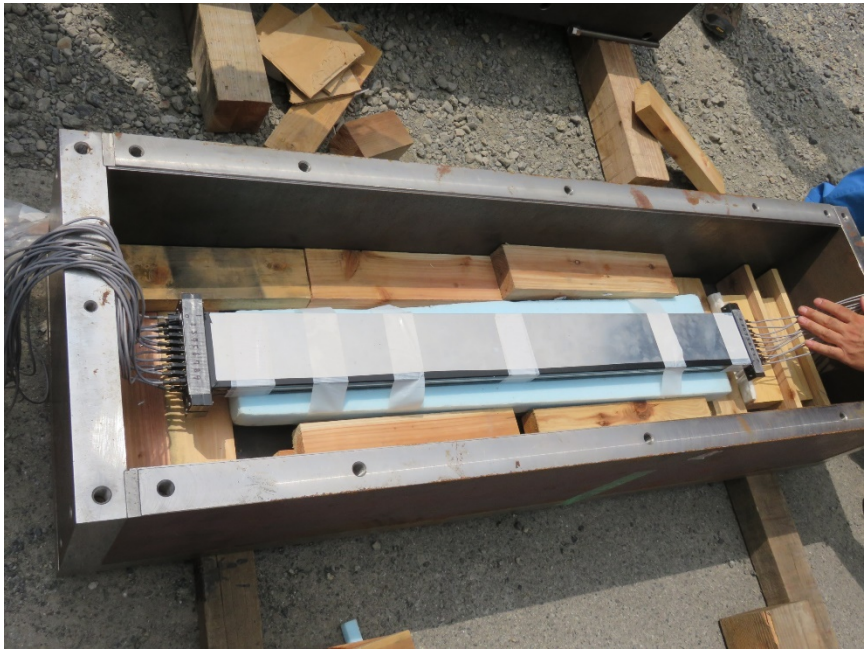


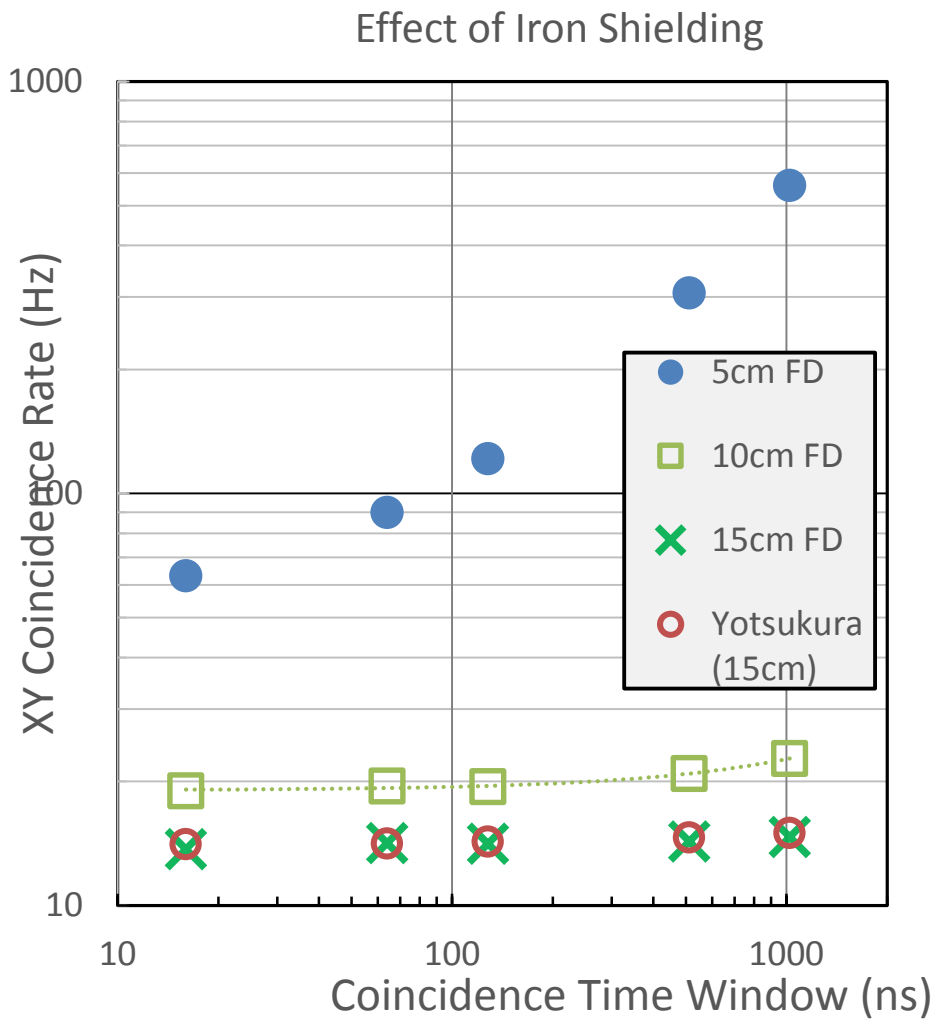
Radiation Survey Map

December 6, 2013 17:00

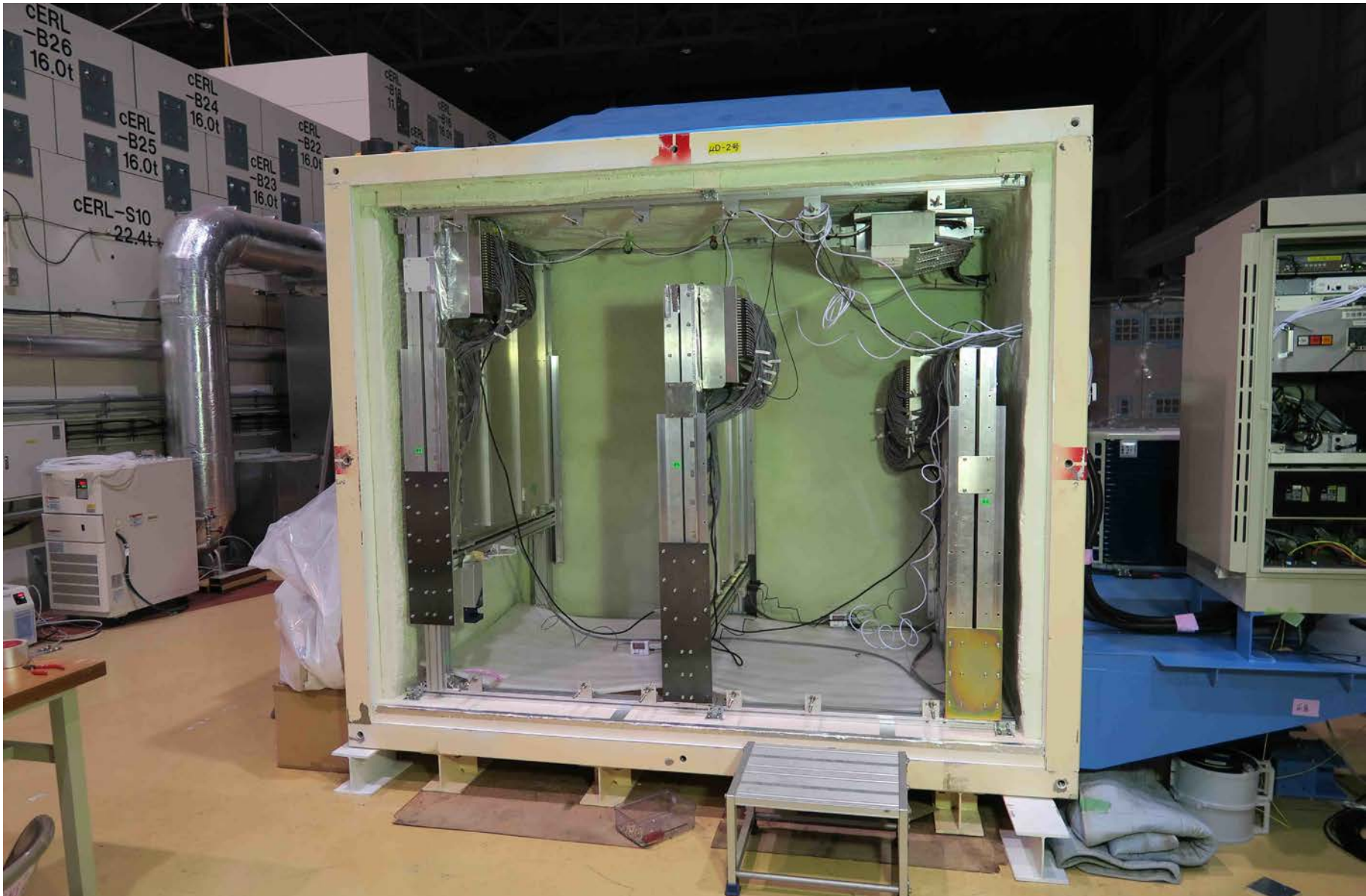


Courtesy of the TEPCO




Effect of Iron Shielding
1000
100
10
XY Coincidence Rate (Hz)
10
100
1000
Coincidence Time Window (ns)
5cm FD
10cm FD
15cm FD
Yotsukura (15cm)

3-3: Detection System



Rough image of Unit1 R/B and T/B～1st floor plan～

Data : Sent to the other building

~20.8m

Assigned Detector Locations

Turbine Building

Equipment entrance

Reactor Building

Main Condenser

Fuel Storage Pool

Bilding Cover

Rad-Waste Building

Service Building

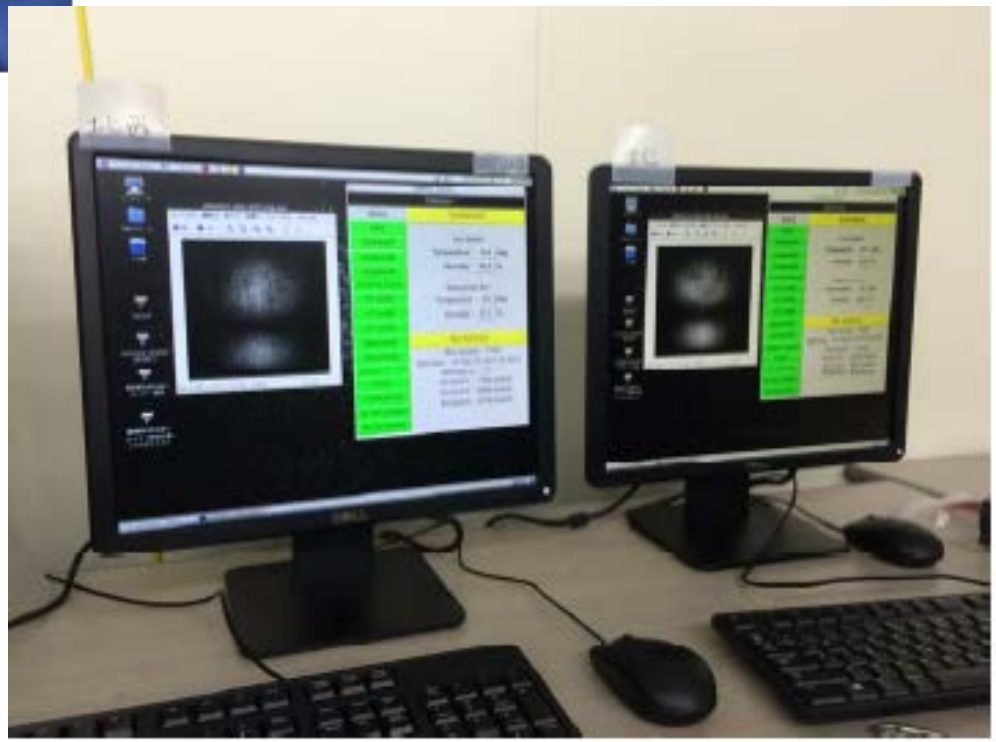
N

A

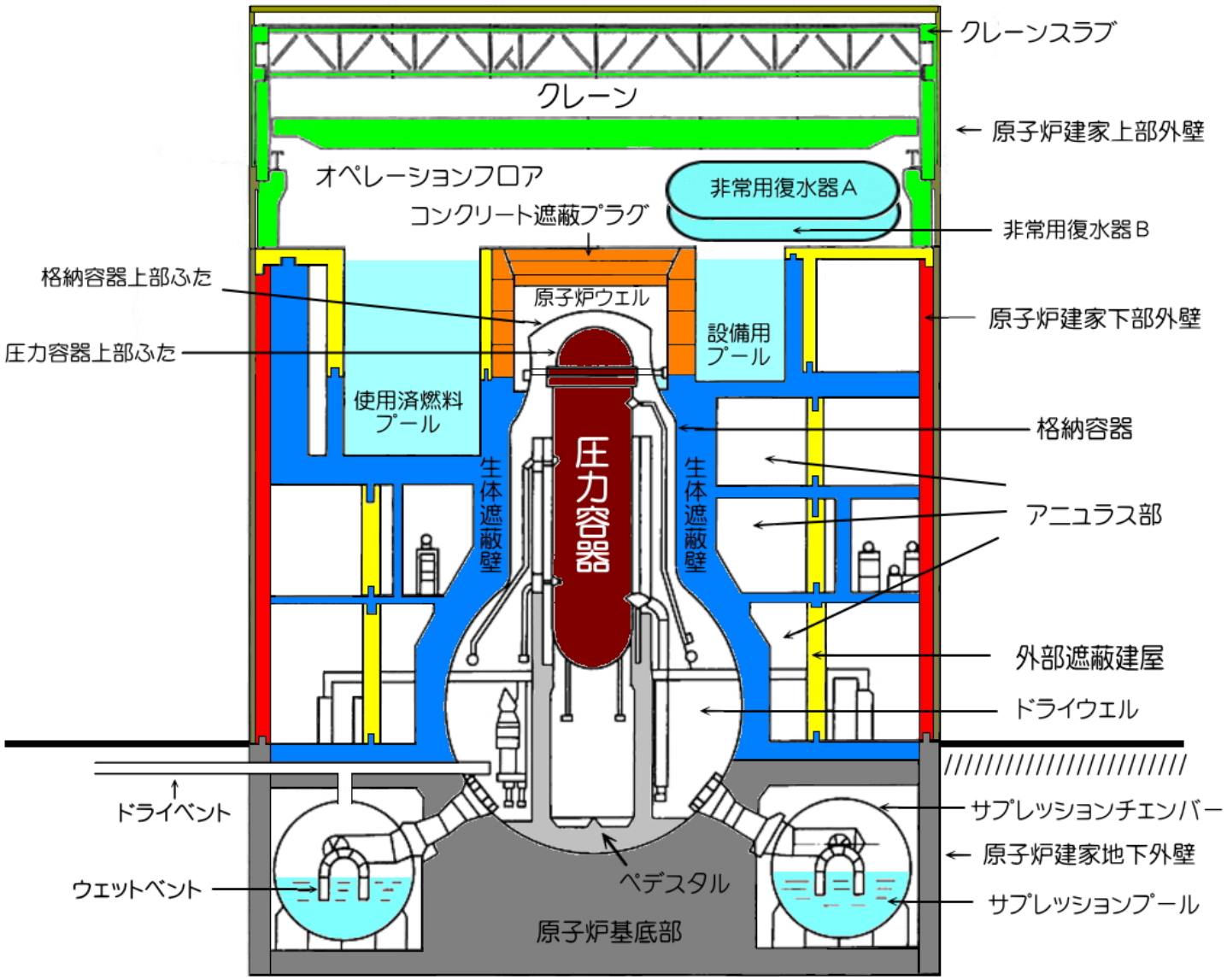
B

タービン建家
機械工作室
6900V開閉装置
タービン蒸気排出装置
原子炉建家
制御棒駆動配管及水圧装置
主復水器
給水加熱器
給水加熱器
湿分分離器
湿分分離器
ディーゼル発電機室
機器搬入口
非常用ディーゼル発電機

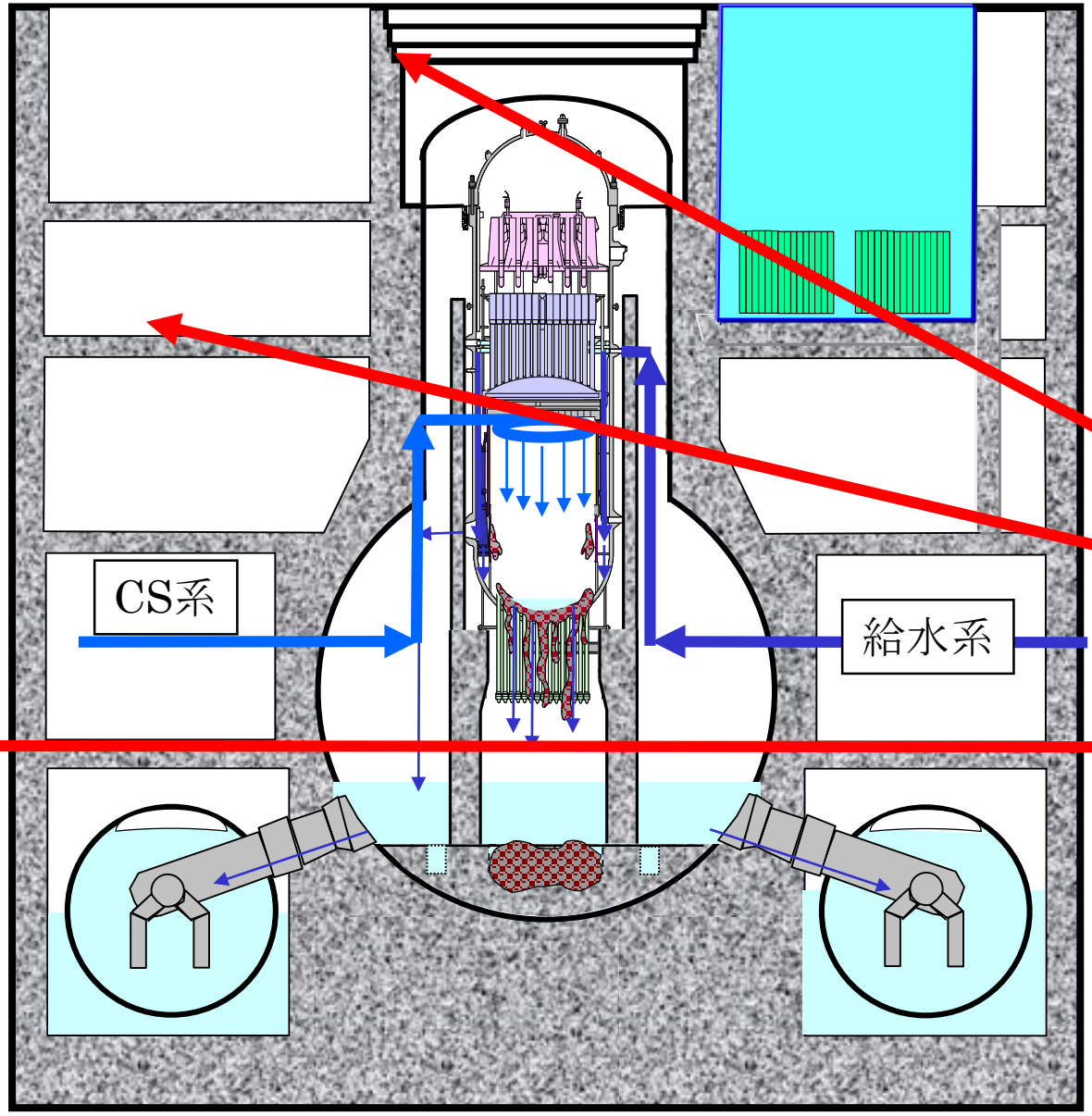
Courtesy of the TEPCO



福島第一　1号　原子炉建家



1号機の炉心・格納容器の状況推定図



・1号機の炉心状態について東京電力は、1号機は原子炉圧力容器内にはほとんど燃料は残っていないと推定

（東京電力　福島第一原子力発電所1～3 号機の炉心・格納容器の状態の推定と未解明問題に関する検討　第1回進捗報告　図6. 1. 1より

なお、使用済燃料プール位置は、福島第一原子力発電[illegible]プ（原子炉建屋内　1[illegible]推定）

測定器

・使用済燃料プー[illegible]は、392体の燃料を貯蔵

（国際原子[illegible]対する日本国政府の追加報告書 東京電力福島原子力発電所の事故について-（第2報）II-126ページより）

地面

3-4 : Present Status of the Study

Measurement of Cosmic Muons

- **from Feb 2015 to Sept 2015**
- **three detector locations outside of the Reactor #1 of the FD**
- **for 90 days**

Detectors are moved away from the reactor site and ceased measurement.

Summary of the measurement at the FD

1: The Structure inside the Reactor Building could be visualized.

2: No hints of objects which are larger than 1m and which stops cosmic rays could not be identified in the PV.

3: Observed image hints for the existence of massive objects in the Nuclear Fuel Storage pool.

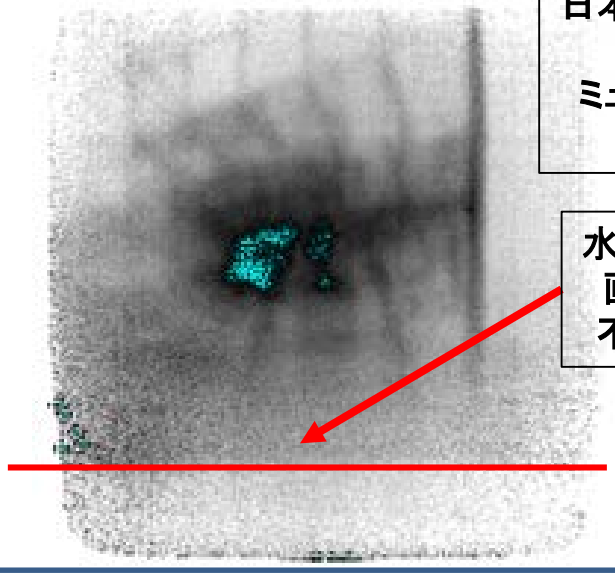
4: At low angles, images of the reactor get less clear and therefore, the existence of the "Nuclear debris" could not be confirmed at the bottom part of the PV.

3-5 : Related Activities

- Measurement of Cosmic Muons at low angles
- Down-sizing of the detection system
- Measurement of Cosmic Muons below the ground level

低角度ミュオンのエネルギー分布測定

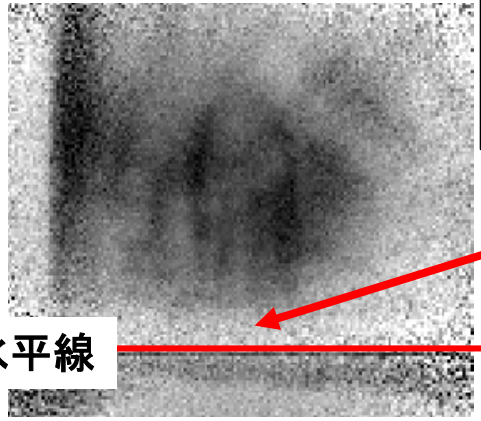
1）観測事実



日本原電東海の原子炉のミュオンによる透視図

水平線の近くで画像が著しく不鮮明になる

2）福島での観測結果



福島1号炉の観測でも水平線の近くで透視図が不鮮明になり圧力容器の底部の観測が困難

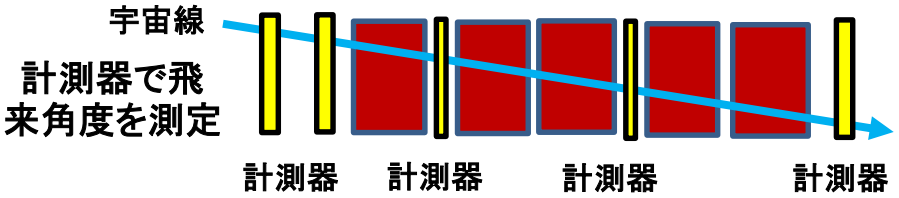
水平線の近くで不鮮明になる

3）推論

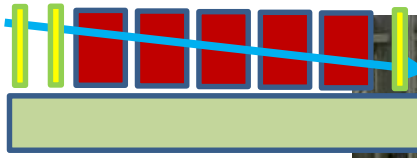
飛来角度が水平線に近づくにしたがって地上に到達して観測される宇宙線のエネルギーが大きくなり物質の透過力が増すことにより構造物の透過画像が不鮮明になる可能性がある

4）低角度ミュオンのエネルギー分布測定

鉄ブロック （通過する鉄の量からミュオンのエネルギーを測定）



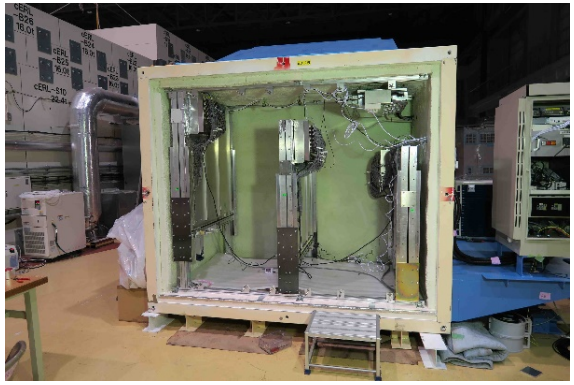
鉄ブロック



コンクリートブロック（実験室外の地平面と計測器設置面のレベルを合わせるためにコンクリートブロックで嵩上げ）

小型ミュオン検出器の製作

1）現在の検出器



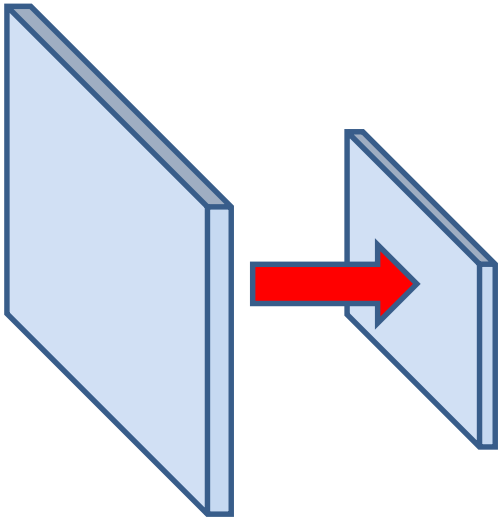
検出器寸法

長さ　2.0 m
幅　1.0 m
高さ　1.8m

外形寸法

長さ　2.5m
幅　2.0 m
高さ　2.1m

2）　小型化



検出器寸法

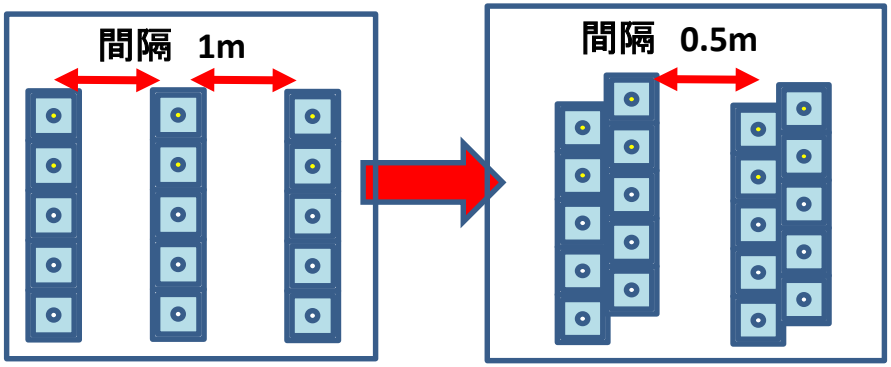
長さ　1.0 m
幅　0.5 m
高さ　1.0m

外形寸法

長さ　1.5 m
幅　1.0 m
高さ　1.5m

3）　測定器は3層構造から2層構造に変更

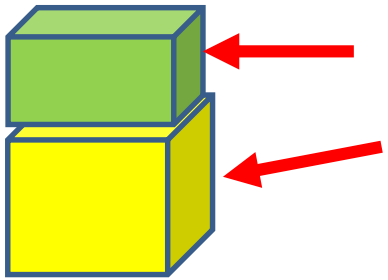
シンチレータ層の間隔が半分になるが
シンチレータを重ねて位置分解能を維持
（これまでの観測で環境放射線量が同じであれば
チャンスコインシデンスによる影響は少ない）



4）　測定器のコンテナーは温度コントロールなし

（MPPCに供給する電圧を個別に調整）
→　断熱層なし　除湿は必要

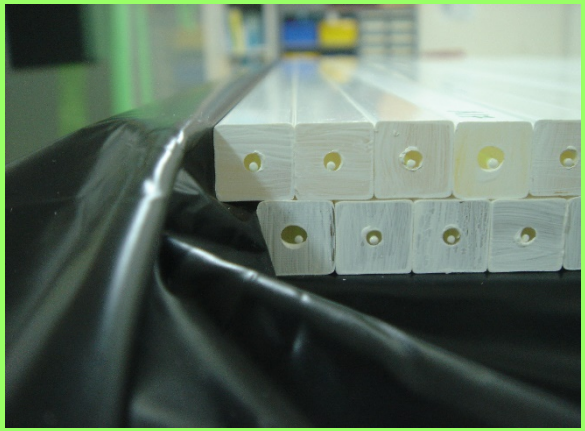
5）　室外機の部分は屋根の上に設置

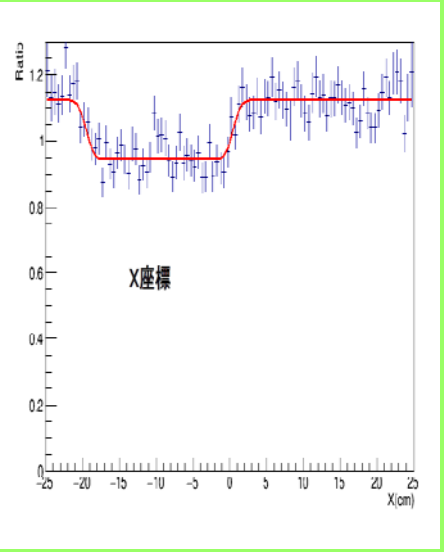


室外器

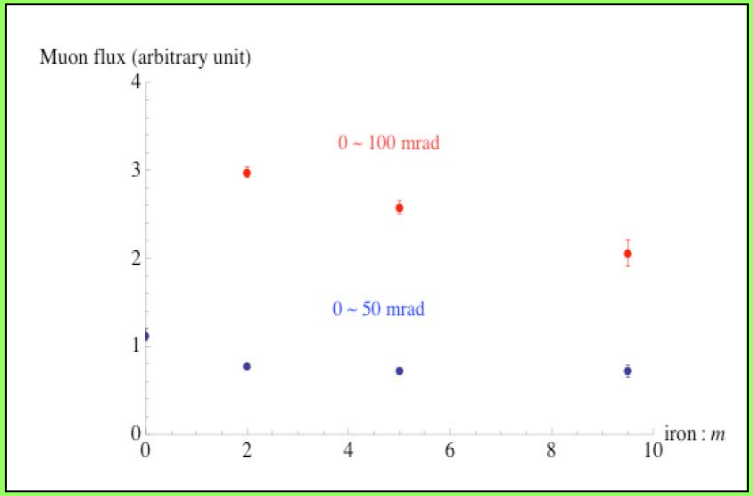
検出器
（10cm の鉄板
で放射線遮蔽）

Detector Down Sizing

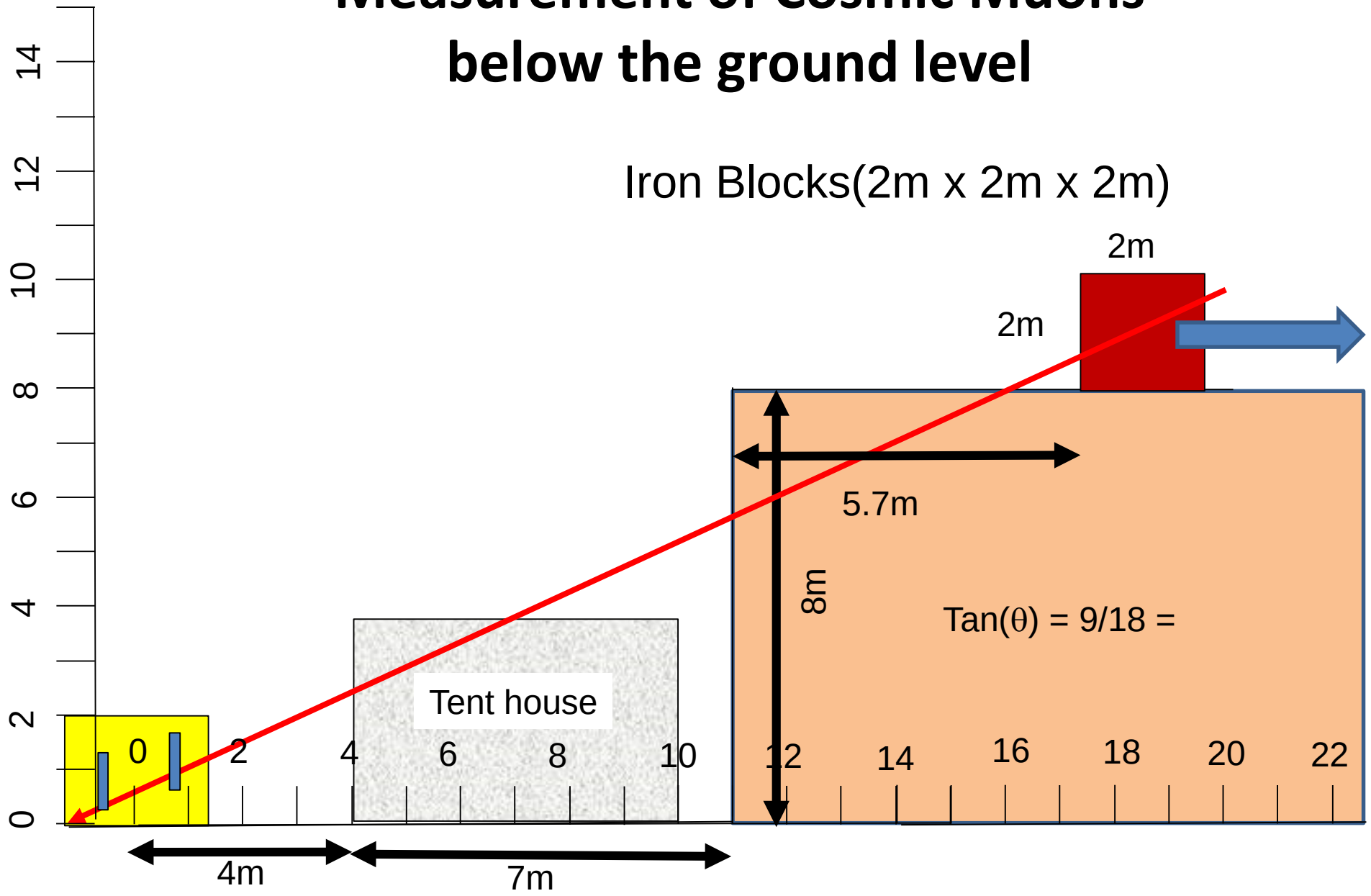




Measurement of muons at the low angles



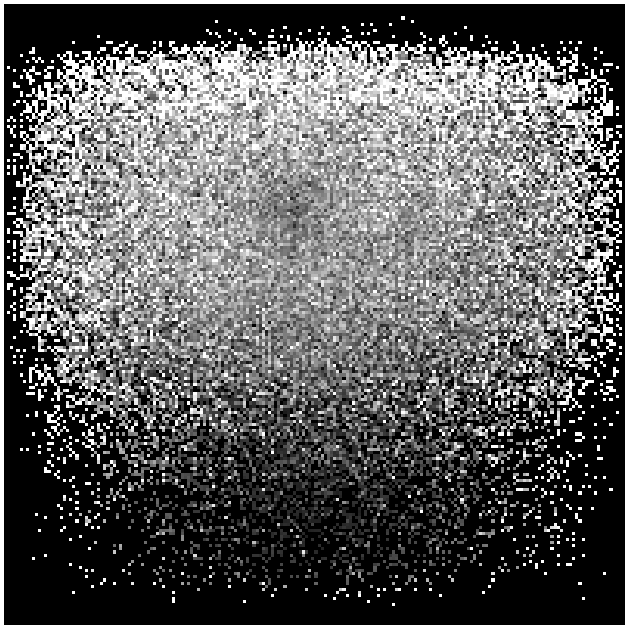
Measurement of Cosmic Muons below the ground level



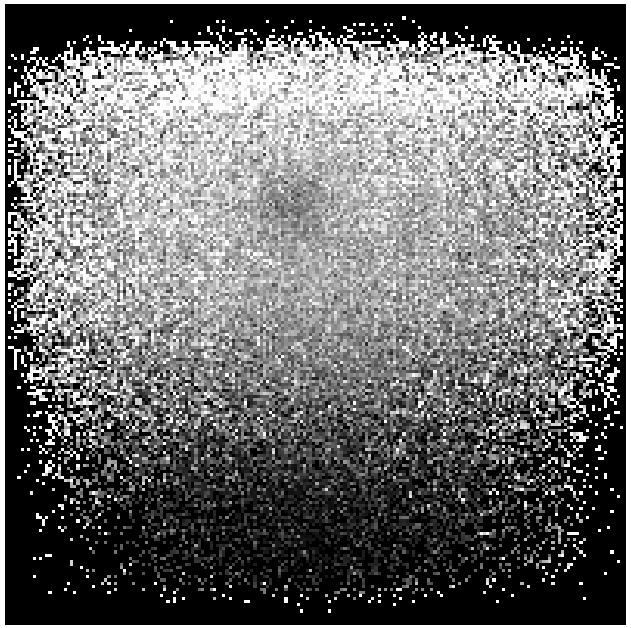

EP1

観測結果

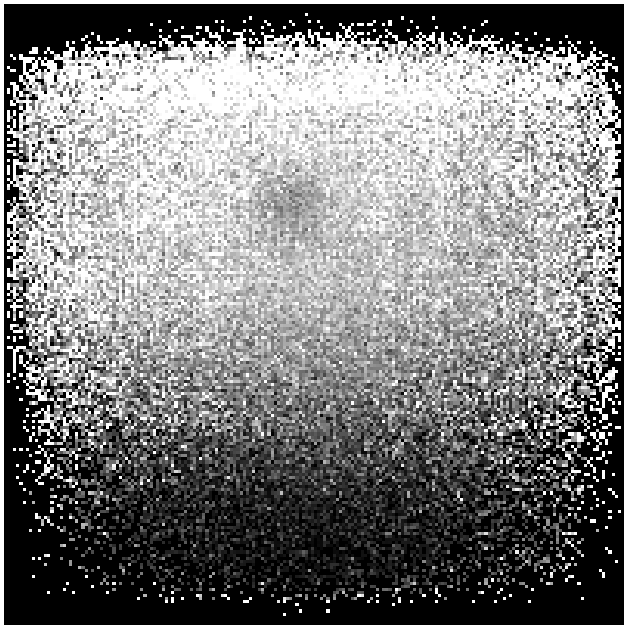
3日



6日



10日



4. Summary

- We have studied the damaged reactor at the Fukushima Daiichi from outside of the reactor building and demonstrated that the CMR can be a useful mean to visualize the damaged reactor.

- However, much more study is needed for getting the detailed images of the reactor.