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Title:	Discussion - Next Step for Fukushima Daiichi Muon Tomography
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Discussion
Next Step for Fukushima Daiichi Muon Tomography

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FMT

- Specification of FMT
  - 18-feet (5.5-m) drift tube, 2-inch (5-cm) diameter
  - 108 tubes per layer
  - Unit layer = 2 layer (detection efficiency: 0.96 x 0.96 = 92%)
  - 12 or 16 layer per module
    - 16 layers allows momentum analysis at 30% level.
  - 2 module per super module (5.5 x 11 m^2)
  - FMT = 2 super module

Discussion 1

- Our standard calculation is based on:
  - Two 60 m^2 trackers (each super-module: 5.5 x 5.5 m^2 x 2)
  - 40-m apart
  - A few weeks to reveal the core, 3 – 4 months for detailed image.

- What is the adequate size for FMT?
  - Measurement time $\propto$ (area 1) x (area 2) / (distance)
  - Sizes of 2 detectors can be different.

- How will FMT powered?
  - Around 10 kW (each super module)

- Is network connection available?
  - Fukushima Daiichi => LANL (20 MB/s)

Drift Tube Test at LANSCE-PSR

Drift tubes less sensitive to γ-ray radiations. 1% efficiency at 1 MeV.
c.f. Scintillation detector (PMT): typically 20%.

A drift-tube detector tested in contaminated sections of LANSCE-PSR (~5 mSv/h).
Major source of the radiation was 835-keV γ ray from ^{54}Mn electron-conversion decay.

Demonstration of the γ-ray attenuation by a concrete shield of 15-cm thickness.

The measured γ-ray background rate:
650 - 800 kHz for 1 mSv/h.
(Normalized for 18-feet tube of FMT.)

Drift Tube Test at LANSCE-PSR

Single and coincidence measured at contaminated sections of LANSCE-PSR.

Raw data. Measured counting rates for detector 1, and 1-and-(2a-or-2b). Detector 1 is top detector; 2a and 2b are bottom detectors.

Radiation Level [mSv/h]	Top [Hz]	Coincidence [Hz]
0.005	1612	20
0.037	5374	163
0.06	7433	319
0.45	65255	19468

High rate at 0.45 mSv/h was caused by random coincidences:

$$r_{12} = 2\tau \times r_1 \times r_2$$
$$= 2 \times 1\ [\mu s] \times 65\ [kHz] \times 130\ [kHz]$$
$$= 17\ kHz$$

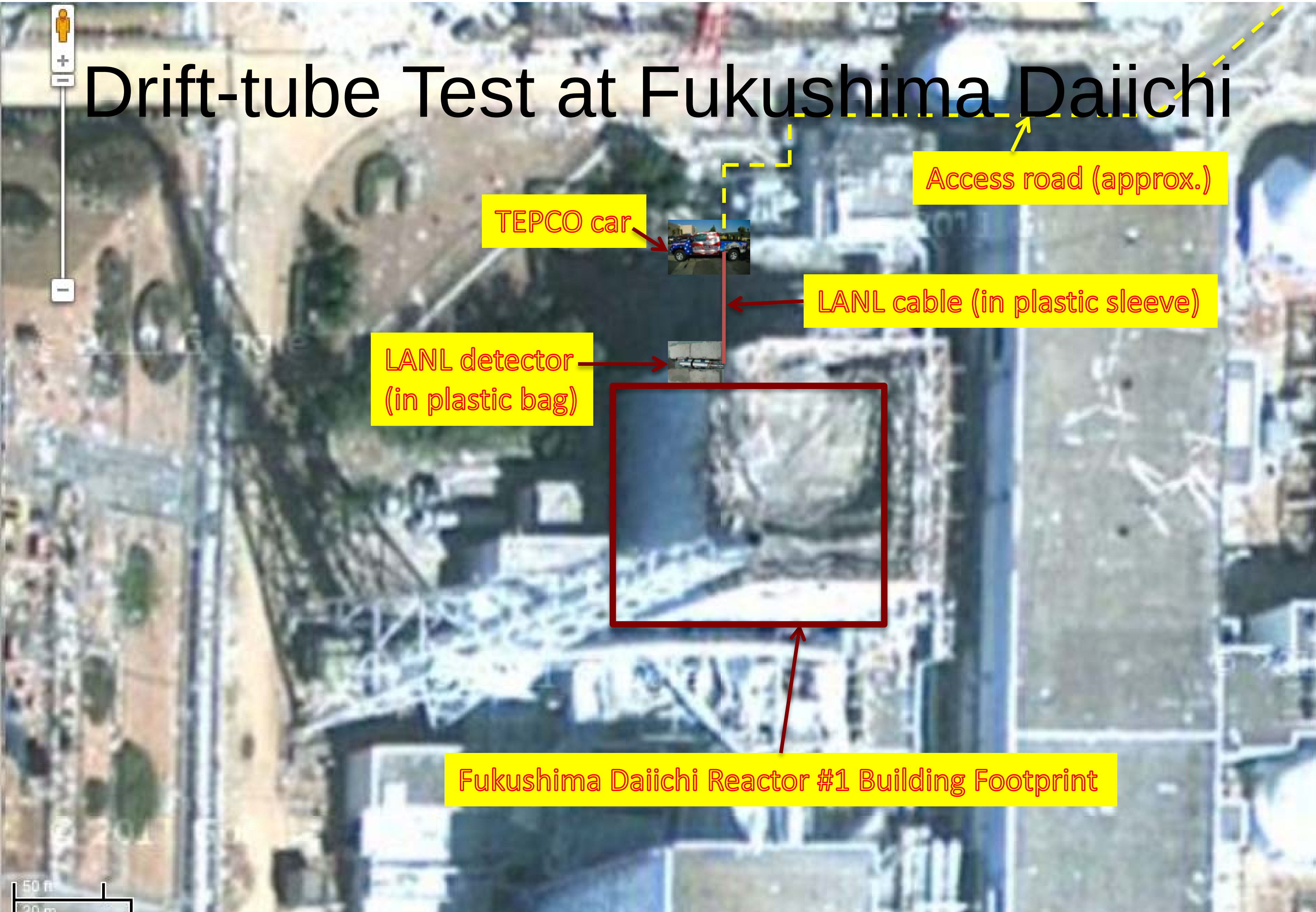
Normalized data for 18-feet tube and for 1 mSv/h .

Radiation Level [mSv]	Top [kHz]	Coincidence [kHz]
0.005	1451	18
0.037	654	20
0.06	557	24
0.45	653	195

The coincidence is caused by:
(1) penetration of Compton scattered electrons, and
(2) scattered γ creating another Compton.

These coincidence event will be 20 kHz per 1 mSv/h.

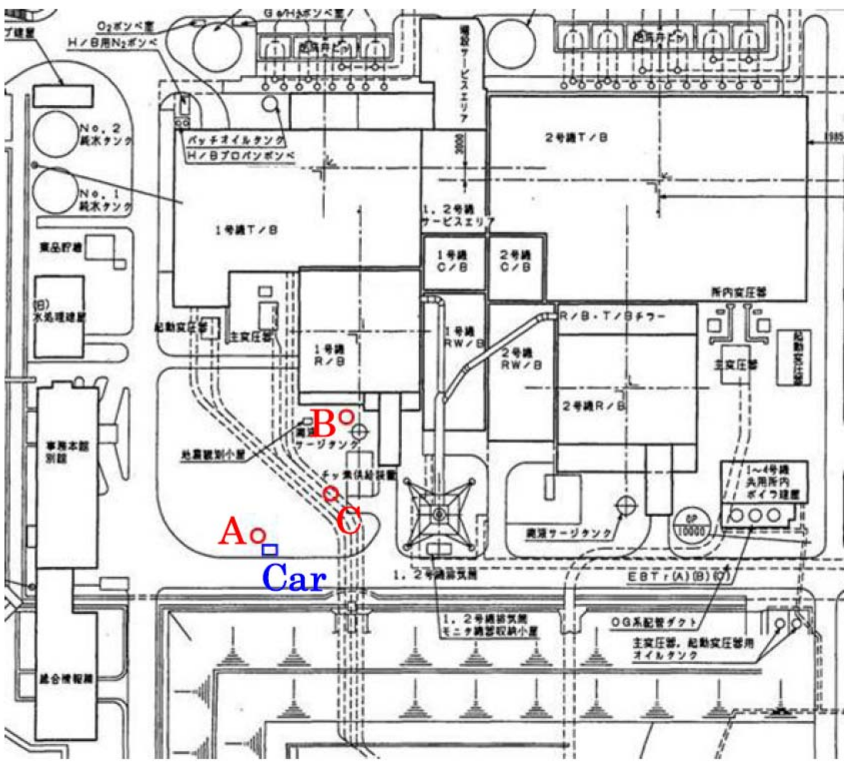
Drift-tube Test at Fukushima Daiichi



Drift-tube Test at Fukushima Daiichi

- Drift-tube tests were performed by TEPCO near Reactor #1.
- The results were consistent with our measurements at LANSCE-PSR.



Conclusion of Drift Tube Test

We estimated background rates of our 18-feet tubes (FMT).

• Expected background rate at Fukushima Daiichi is ~1 MHz per 1 mSv/h. Though most of the background can be removed by taking a 2-layer hardware coincidence, we would like to keep each tube under 6 kHz to prevent accidental coincidence.

• Reduce the γ-ray background by a factor of 170.
1000 should be safe enough.

• We estimated the radiation shield thickness required for FMT.

$$I = B\, I_0 \exp(-\mu x/\rho)$$

The buildup factors are calculated by several authors with Monte Carlo simulations.
A. Shimizu *et al.*, J. *Nucl. Sci. and Tech.* 41 (2004) 413.

Estimation of Background

To reduce the γ-ray from cesium by 3 orders of magnitude:

Concrete 0.6 m,
Water 1.25 m, or
Iron 0.175-m

are needed.

Attenuation of γ rays from ^{134}Cs, ^{137}Cs, and their daughter nuclide by concrete of 0.6-m thickness. Shield effect: 9.6×10^{-4}.

E [keV]	B.R. [%]	λ [cm]	Attenuation	B.F.	At x BR x BF
Cs134					
563	8.4	5.2	1.0E-05	34.7	2.9E-05
569	15.4	5.2	1.1E-05	33.2	5.4E-05
605	97.6	5.4	1.5E-05	31.6	4.5E-04
796	85.5	6.1	5.4E-05	25.3	1.2E-03
802	8.7	6.1	5.6E-05	25.2	1.2E-04
1,365	3	7.9	4.9E-04	14.7	2.2E-04
Cs137					
662	85.1	5.9	3.6E-05	27.2	8.4E-04

Attenuation of γ rays from ^{134}Cs, ^{137}Cs, and their daughter nuclide by water of 1.25-m thickness. Shield effect: 1.3×10^{-3}.

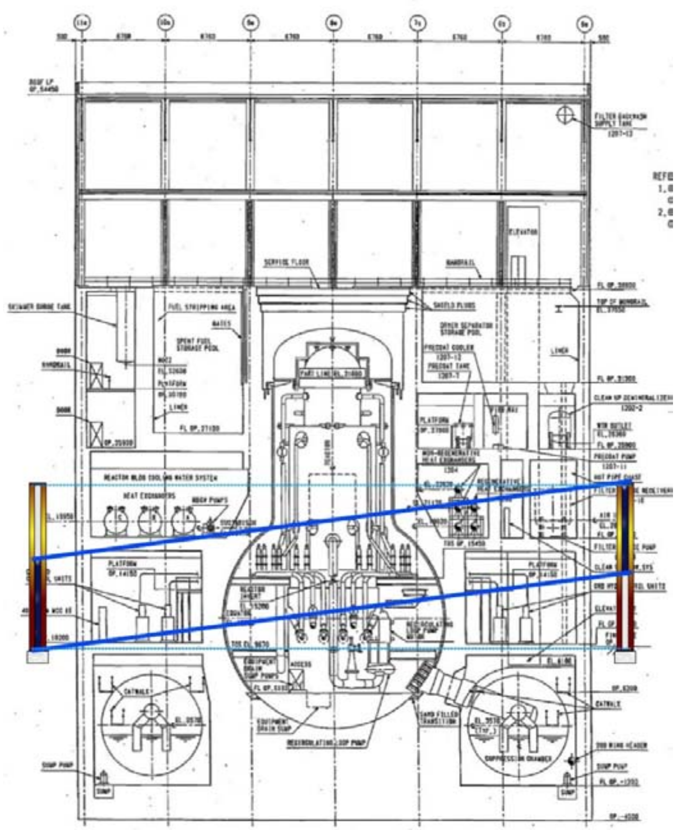
E [keV]	B.R. [%]	λ [cm]	Attenuation	B.F.	At x BR x BF
Cs134					
563	8.4	10.8	9.8E-06	43.1	3.5E-05
569	15.4	10.9	1.0E-05	53.3	8.5E-05
605	97.6	11.2	1.4E-05	48.8	6.8E-04
796	85.5	12.7	5.2E-05	34.6	1.5E-03
802	8.7	12.7	5.4E-05	34.2	1.6E-04
1,365	3	16.4	4.8E-04	19.3	2.8E-04
Cs137					
662	85.1	12.2	3.5E-05	38.9	1.2E-03

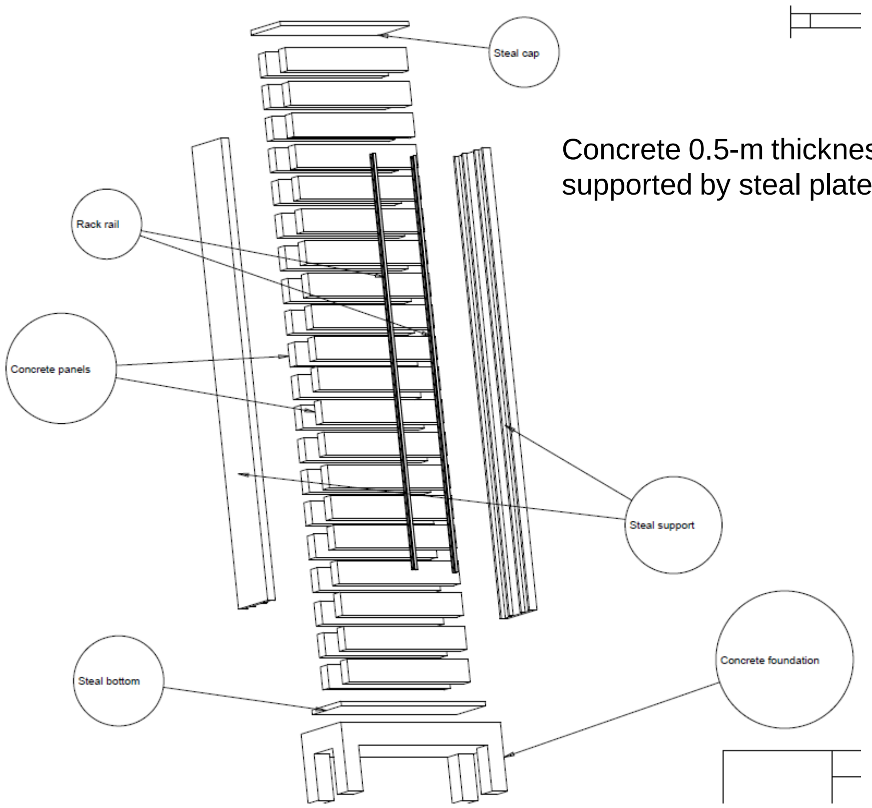
Attenuation of γ rays from ^{134}Cs, ^{137}Cs, and their daughter nuclide by iron of 0.175-m thickness . Shield effect: 1.1×10^{-3}.

E [keV]	B.R. [%]	λ [cm]	Attenuation	B.F.	At x BR x BF
Cs134					
563	8.4	1.6	1.6E-05	19.1	2.7E-05
569	15.4	1.6	1.7E-05	19.1	5.2E-05
605	97.6	1.6	2.5E-05	19.1	4.6E-04
796	85.5	1.9	9.3E-05	17.6	1.4E-03
802	8.7	1.9	9.6E-05	17.6	1.5E-04
1,365	3	2.4	7.7E-04	13.5	3.1E-04
Cs137					
662	85.1	1.8	6.2E-05	18.1	9.5E-04

Setup at Fukushima Daiichi

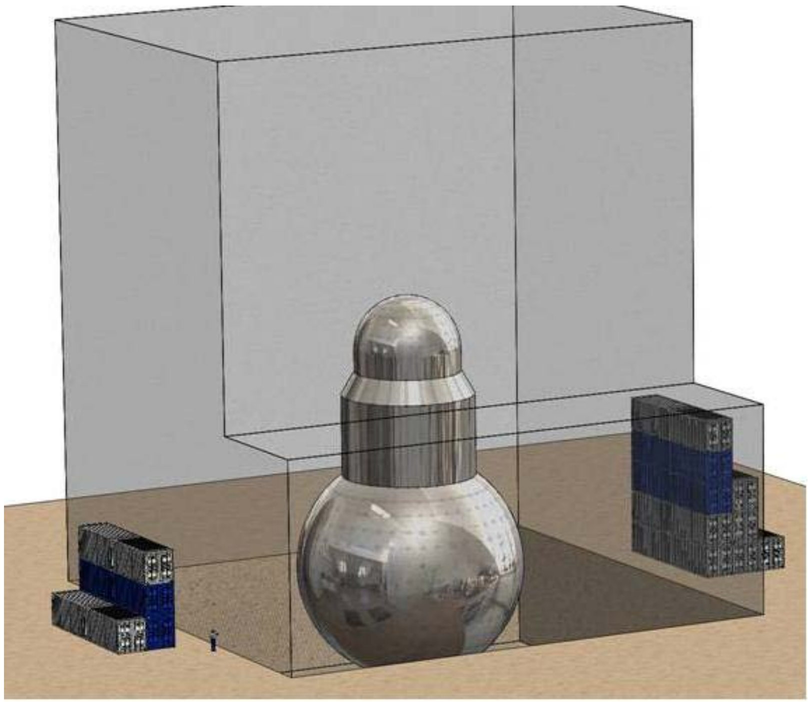
Two detectors sandwiching a reactor building.
Detection area: 5.5 x 11 m^2.
Detector height can be changed remotely inside the radiation shield: 0 ~ 14.5 m.
The shield design was verified by a Japanese construction office.





Concrete 0.5-m thickness
supported by steal plates.

Setup at Fukushima Daiichi

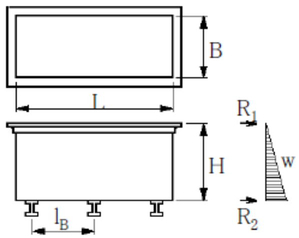


A standard shipping container will hold detectors and water tank radiation shields

Water Tank for FMT

RECTANGULAR TANKS
Eugene F. Megyesy "PRESSURE VESSEL HANDBOOK" Thirteenth Edition

	material for plate and bottom plate	SA 283 C	
	material for stiffening frame		
	material for bottom support		
	design temperature		°C
G =	specific gravity of liquid	1.0	
B =	width of tank	660	mm
H =	height of tank	2315	mm
L =	length of tank	5823	mm
l_B =	spacing of bottom support		mm
S =	stress value of plate	108.248	MPa
E =	modulus of elasticity for stiffening frame material	206842.7	MPa
Sb =	stress value of bottom support	108.248	MPa
c =	corrosion allowance	0	mm
ta =	actual plate thickness	30	mm
	moment of inertia for top-edge stiffening ANGLE 1-3/4 x 1-3/4 x 3/16		mm^4
	actual bottom plate thickness	30	mm
	section modulus of bottom support		mm^3
d =	constant (density of water)	9.80665×10^{-6}	N/mm
β =	constant	0.056	



Ratio, H/L	0.25	0.286	0.333	0.4	0.5	0.667	
Constant, β	0.024	0.031	0.041	0.056	0.080	0.116	
Ratio, H/L	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Constant, β	0.16	0.26	0.34	0.38	0.43	0.47	0.49

t = required plate thickness = $L\sqrt{[\beta HdG/S]} + c$ — 19.96 mm

Design is acceptable

w = load per unit of length = $dGH^2/2$ — 26.28 N/mm

Steal 3-cm thickness is required for the water tank.

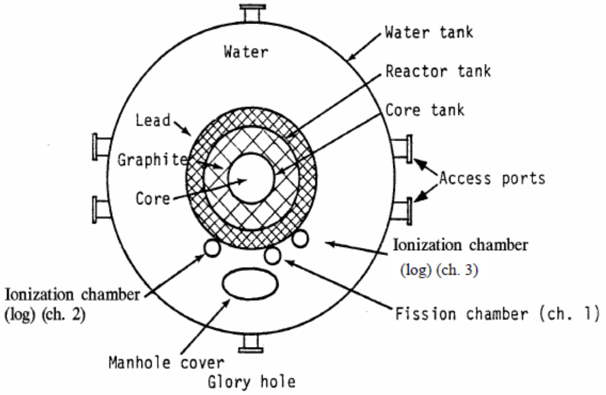
- 8.8 ton x 2(empty) + side
- 17.6 ton x 2 (water loaded) + side

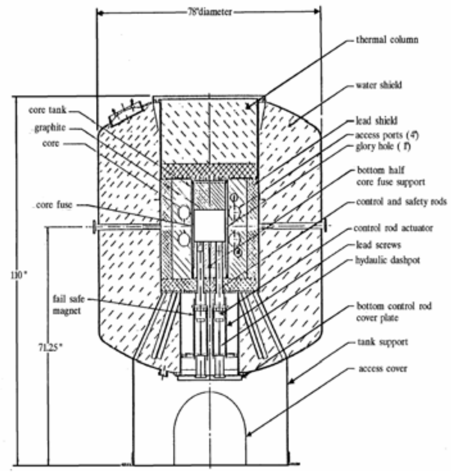
Special container needed.

Discussion 2

- What should be our plan for radiation shield?
    - Concrete or water?
    - Installation method?
    - Japanese construction company available at Fukushima Daiichi?

Demo at UNM Reactor





Core : 25.6-cm diameter by 24-cm high (nine fuel discs).
19.5% enriched UO_2 powder embedded in radiation-stabilized polyethylene moderator. The amount of uranium in the core is 3.4 kg with average density of 0.28 g/cm^3.
The density of the uranium fuel is only 1/10 of Fukushima Daiichi reactors, and we do not expect to see the fuel clearly. However, we will see the structures of the reactor.

Demo at UNM Reactor

By deploying MMT next to a research reactor, we will be able to measure the impact of low level radiation fields on muon tomography and reconstruction processes.

Radiation level during reactor operation is ~50 μSv/h which provides similar radiation environment of inside the FMT radiation shield at Fukushima Daiichi.

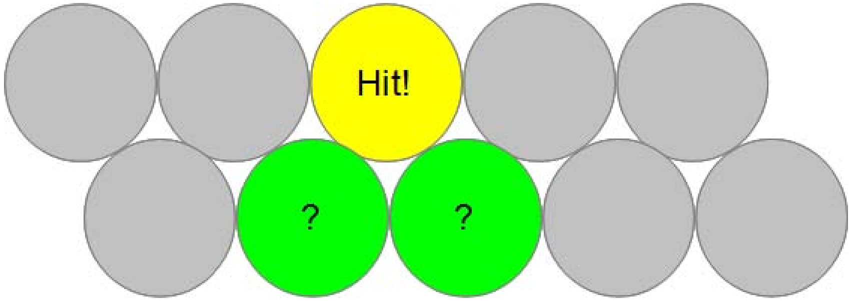
We will implement coincidence algorithm on the FPGA board.

DAQ Improvement

Time-coincidence logic to our electronics to remove high γ-ray background.

The coincidence can be implemented with minor modifications to the existing FPGA code and can reduce most of the γ-ray events.

The new algorithm will be tested during the technical demonstration at UNM.



SUKU

Test engineering issues of FMT

- System installation and readiness of testing process.
- Time synchronization of two modules (GPS).
- Remote operation. Data transfer from Fukushima Daiichi to LANL.

<u>SUKU</u>
Two compact detectors each consisted of 24 tubes (2-inch diameter, 1-foot length, 6 tubes x 4 layers).

Initial engineering / operation tests of SUKU at LANL (Staging Area, TA-53).
Install SUKU at Fukushima Daiichi at possible installation points of FMT.

Goal: find any possible failure mode of the system and to establish the recovery method.
A 2-week measurement at Fukushima Daiichi will essentially demonstrate engineering / operational features of our technique so that the Japanese decision makers can support FMT installation with confidence.

Discussion 3

- System test at Fukushima Daiichi?

    - Purpose of SUKU is to demonstrate engineering / operational features of our technique so that the Japanese decision makers can support FMT installation with confidence.
    - Except for the radiation shield, other features can be tested at LANL.

- Alternative to SUKU is to test drift tubes in a concrete shield at Fukushima Daiichi.
    - Detector test instead of system test.
    - Confirm shield thickness.

Discussion 3

Schedule?

Stage 0 (completed)
- Technical demonstration with mockup reactor.
- Drift tube tests under high radiation.
- Radiation shield calculation.
- Simulation studies on reactor tomography.
- Development of reactor-imaging algorithm.
- Project plan.

Stage 1 (August ’12 – October ’12)
- Technical demonstration with research reactor at University of New Mexico (UNM).
- DAQ improvement to remove □-ray background.
- Detailed simulation on Fukushima Daiichi reactors.
- Detailed project plan and cost estimate.

Stage 2 (September ’12 – February ’13 ?)
- Operation tests at Fukushima Daiichi with a small detector system.
- System optimization / software improvements.

Discussion 3

Stage 3A (January ’13 – April ’13 ?)

- Design and manufacture radiation shields.
- Manufacture and test FMT.
- Final optimization of the system and software.

Stage 3B (July ’13 – July ’14 ?)

- Installation of FMT to Fukushima Daiichi.
- Image reactor #1 – 3.