TIPP '14

CHIBA UNIVERSITY

CHUBU Electric Power

科研費 KAKENHI

4 June 2014 / Amsterdam in The Netherlands
V.b Health & Bio

Development of Real time ^{90}Sr counter applying Cherenkov light detection

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Outline

1. Problems
2. Method of ^{90}Sr measurement
3. ^{90}Sr Counter
   - Mechanism
   - Performance measurement
4. Discussion
5. Summary

Thanks for the grant of KAKENHI.
Thanks for the grant of Chubu Electric Power Co., Inc.

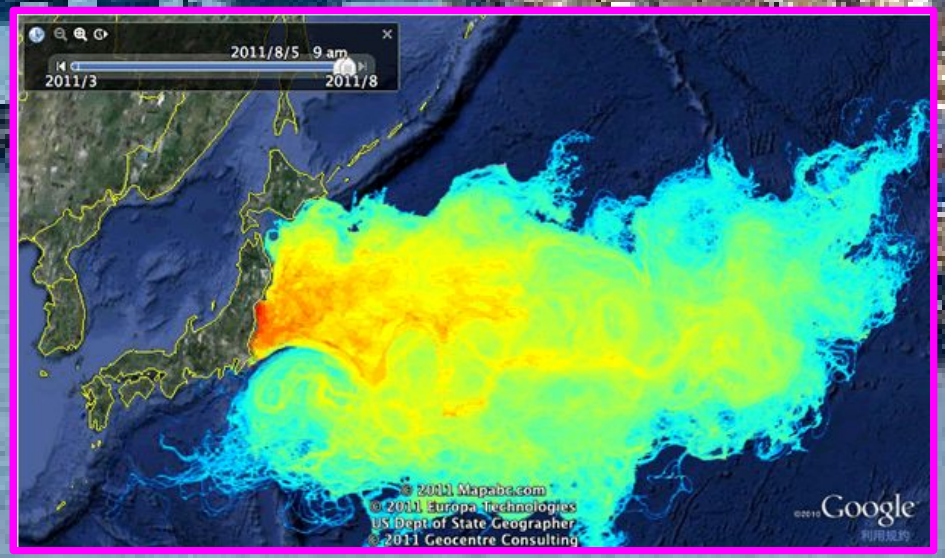
Nuclear Accident at the Fukushima Daiichi Nuclear Power Station in March 2011

No.4 plant

No.2 plant

No.3 plant

No.1 plant



main isotope by a nuclear reactor

^{131}I	8 days	β , γ
^{137}Cs	30 years	β , γ
^{90}Sr	29 years	β
^{239}Pu	24120 y	α
^{85}Kr	10 years	β
^{89}Sr	50 days	β

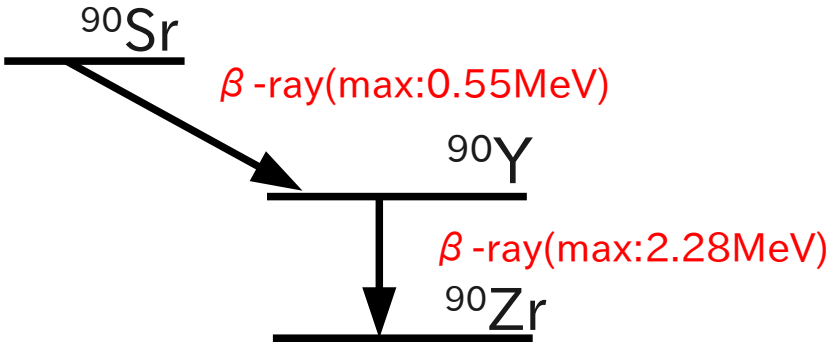
A problem of radioactive contamination

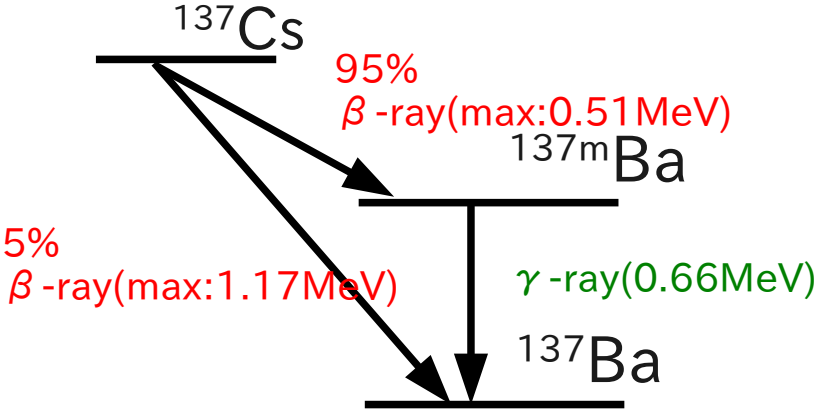
^{90}Sr/^{90}Y

Phys. Half-life :29 years
Bio. half life :49 years
Eff. half-life :18 years

^{137}Cs

Phys. Half-life :30 years
Bio. half life :70 days
Eff. half-life :70 days





$$\tau_{eff}^{-1} = \tau_{phy}^{-1} + \tau_{bio}^{-1}$$

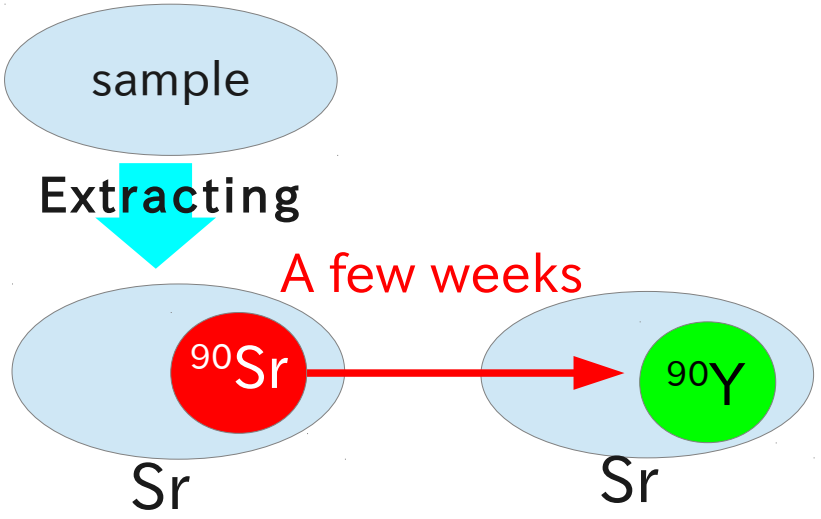
τ_{eff} : effective half-life
τ_{phy} : physical half-life
τ_{bio} : biological half-life

In the contamination water, ^{90}Sr has more dangerous and difficult identification than ^{137}Cs.

Measurement method of concentration for ^{90}Sr

method1

A Sr is able to be measured a concentration by to extract chemically. A few weeks After the extracting, ^{90}Sr is estimated the concentration from measurement of ^{90}Y.

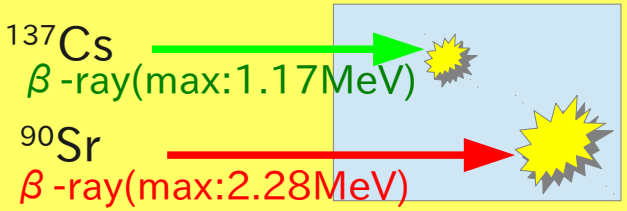


method2

Measurement of β-ray from a sample
(1)Energy calorimeter
(2)Range counter
(3)Cherenkov counter

(1)Energy calorimeter

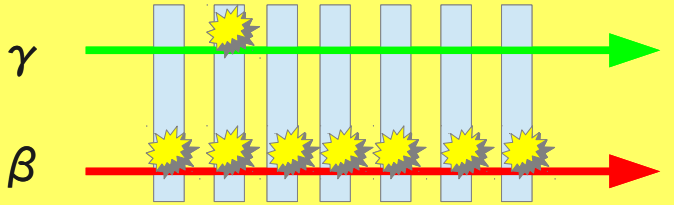
This device measures a deposition energy of beta-ray. The beta-ray from ^{90}Sr deposits more than ^{137}Cs.



Not Real-time count

(2)Range counter

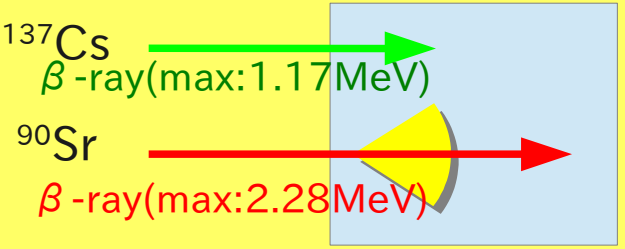
This device identifies gamma-ray and beta-ray using multilayer detectors and this counter decides the ^{90}Sr by the many reactions of beta-ray detection.



Real-time count

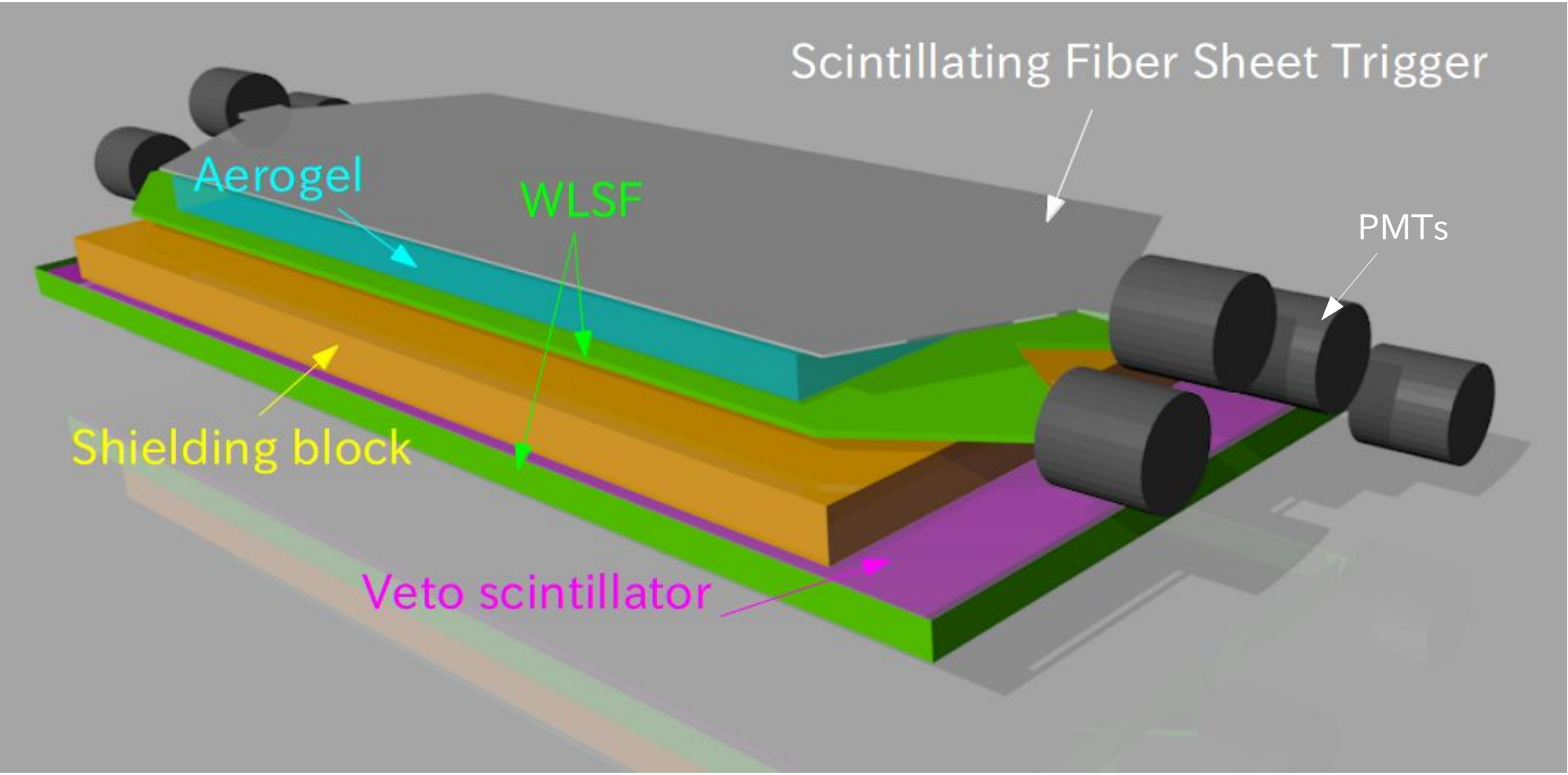
(3)Cherenkov counter

This device is threshold type of the beta-ray's velocity from ^{90}Sr and ^{137}Cs.



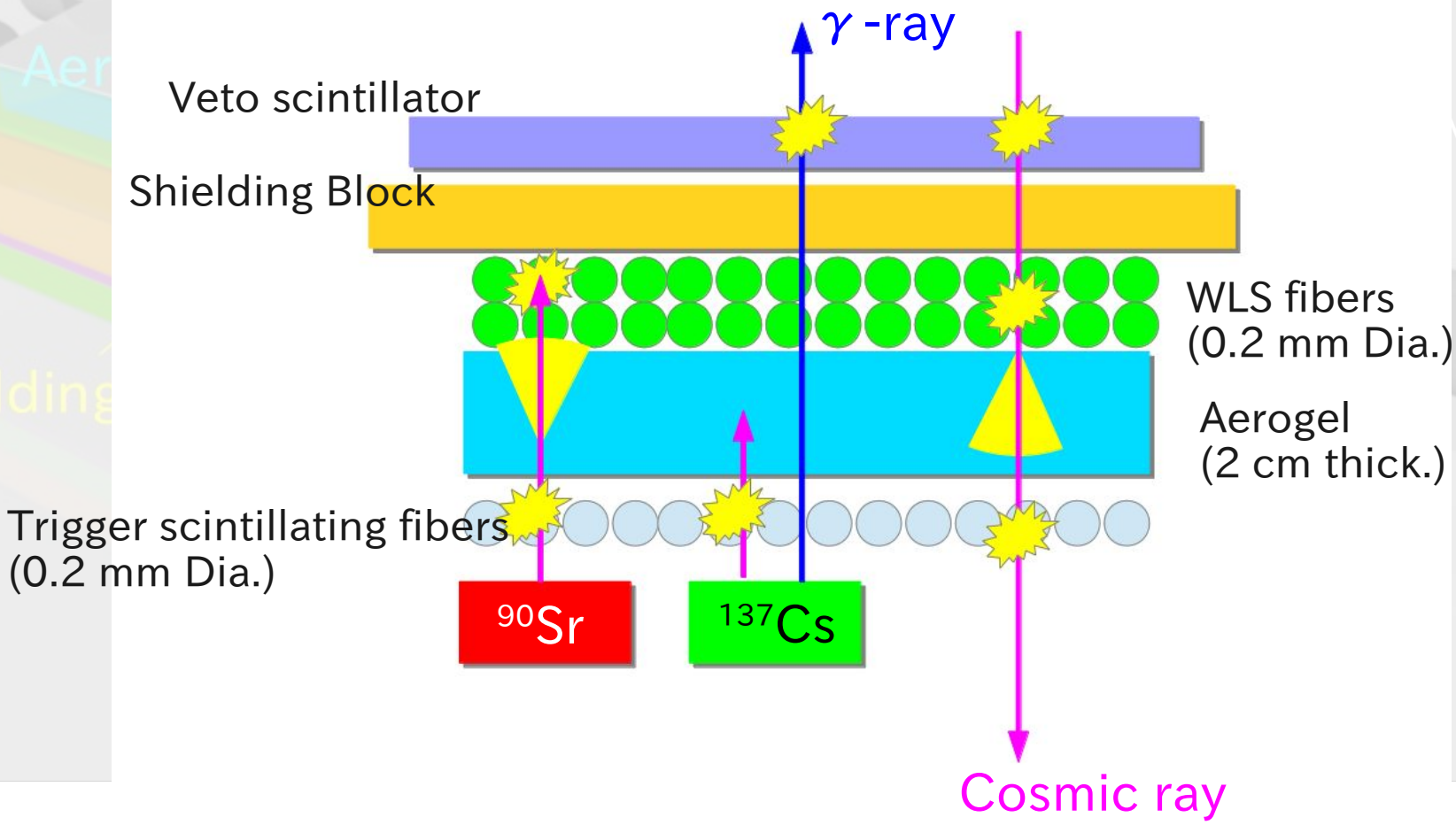
Real-time count

Development of ^{90}Sr Counter



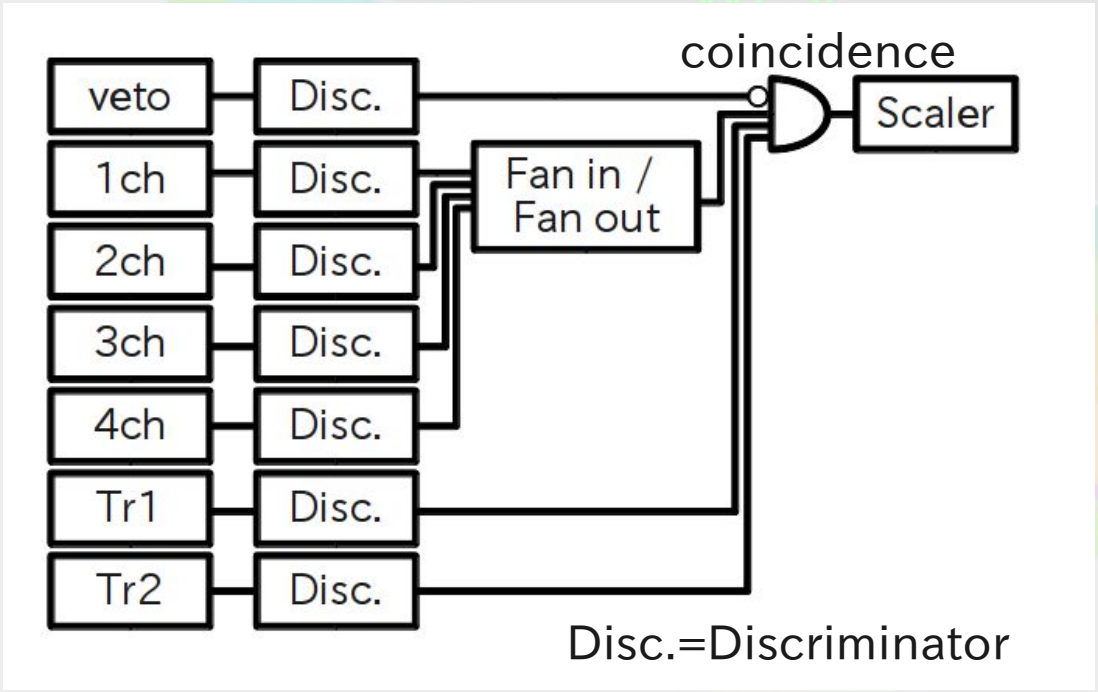
Development of ^{90}Sr Counter

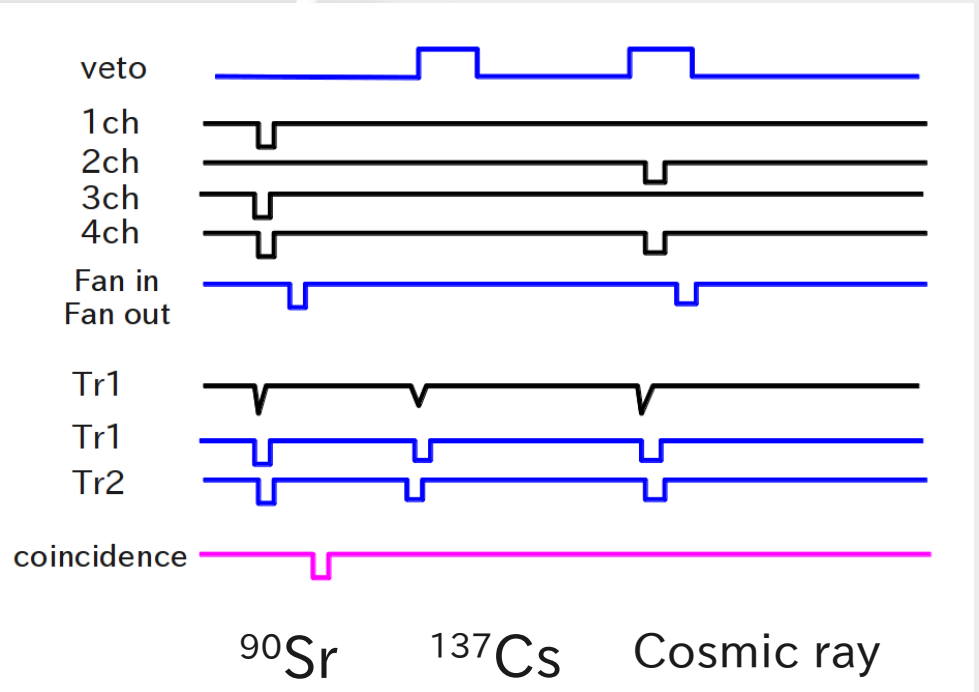
Development of ^{90}Sr Counter
Detection mechanism



Development of ^{90}Sr Counter

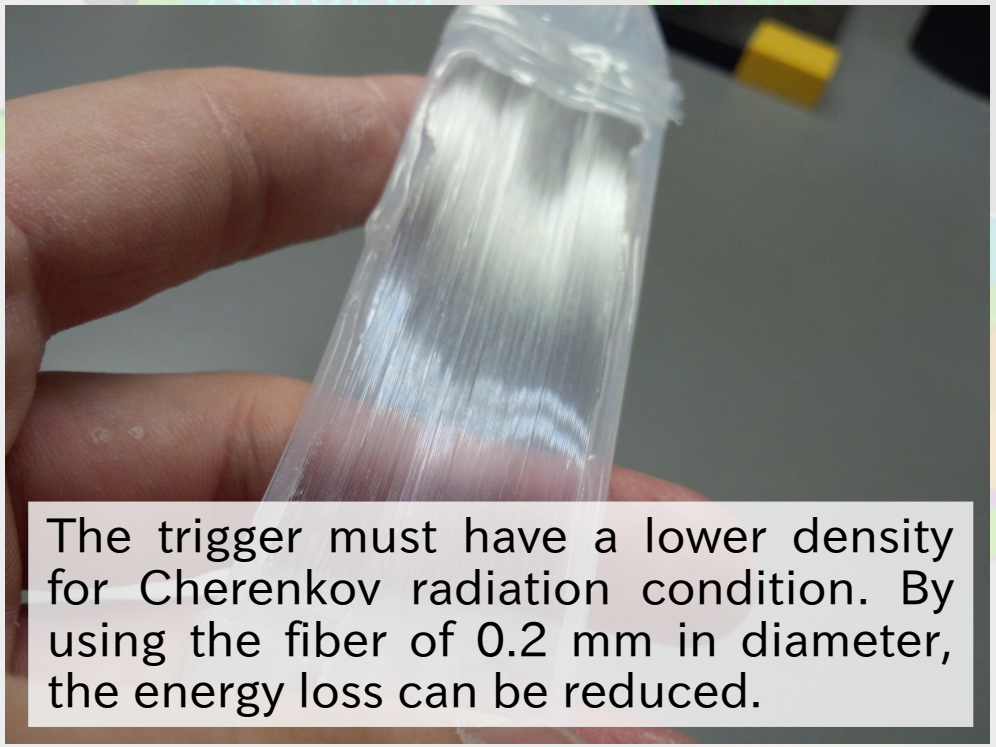
Detection Logic





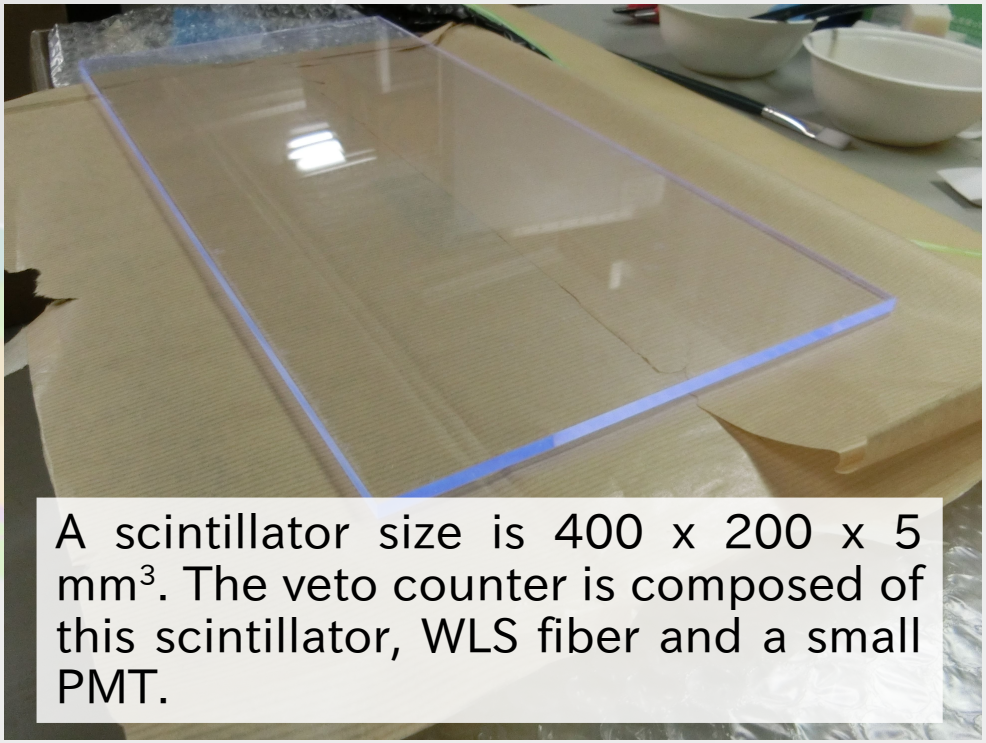
Development of ^{90}Sr Counter

Trigger fiber



The trigger must have a lower density for Cherenkov radiation condition. By using the fiber of 0.2 mm in diameter, the energy loss can be reduced.

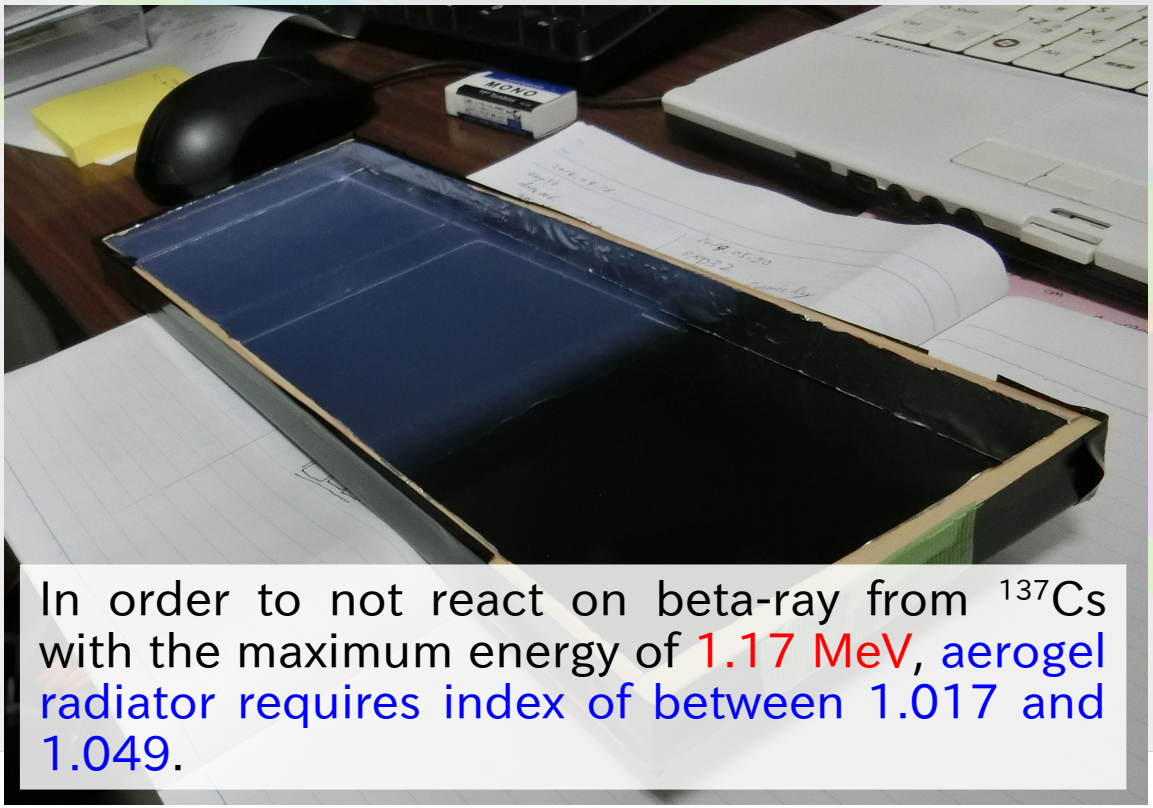
Veto scintillator



A scintillator size is 400 x 200 x 5 mm^3. The veto counter is composed of this scintillator, WLS fiber and a small PMT.

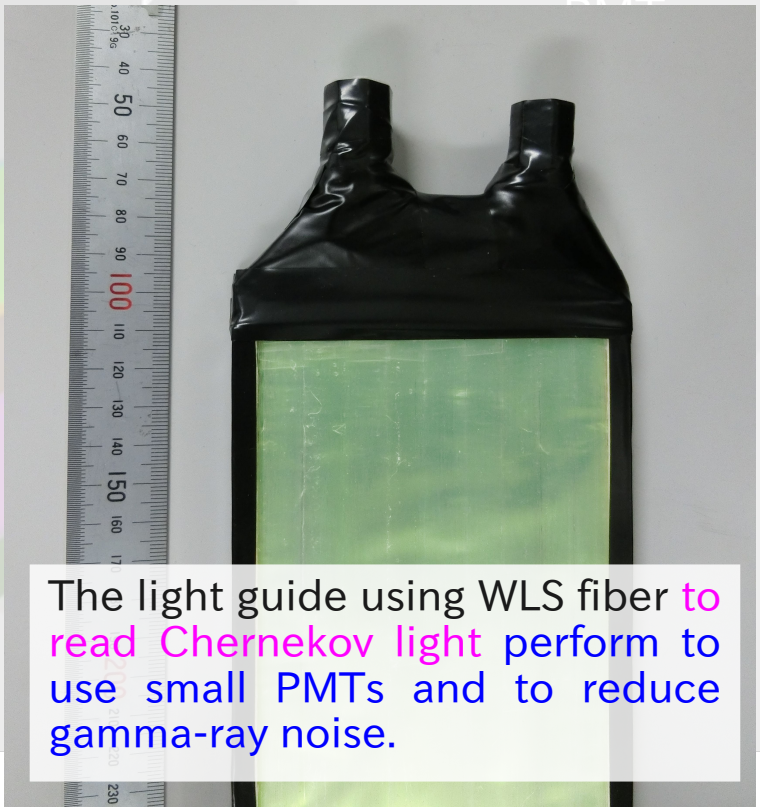
Development of ^{90}Sr Counter

Aerogel



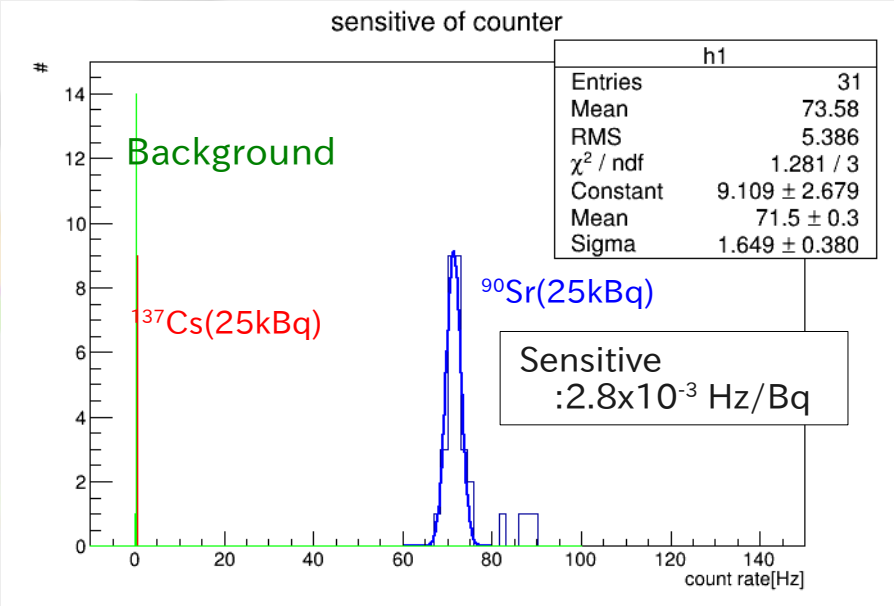
In order to not react on beta-ray from ^{137}Cs with the maximum energy of 1.17 MeV, aerogel radiator requires index of between 1.017 and 1.049.

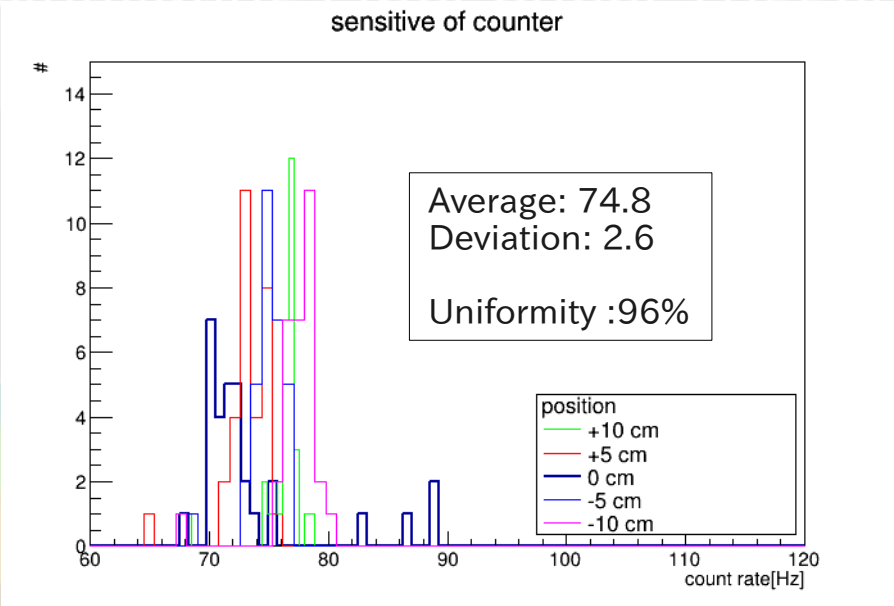
WLS fiber

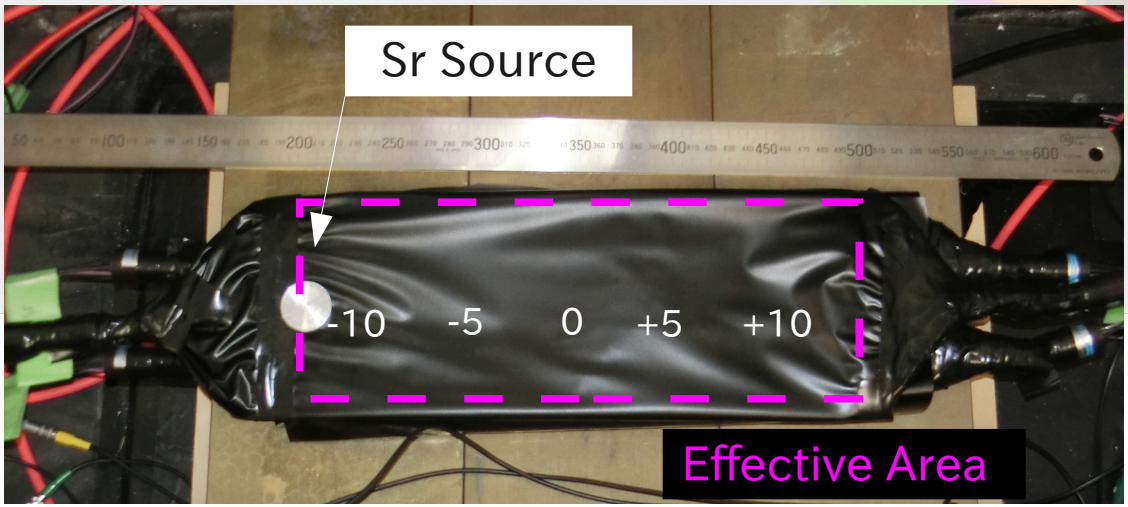


The light guide using WLS fiber to read Chernekov light perform to use small PMTs and to reduce gamma-ray noise.

Development of ^{90}Sr Counter Performance







Prototype

Effective area :	30 x 10 cm^2
^{90}Sr sensitivity :	2.8 x 10^{-3} Hz/Bq
^{137}Cs sensitivity:	6 x 10^{-6} Hz/Bq
BG noise ratio	0.28 Hz
Sr/Cs ratio:	500
Position uniformity :	96%

Discussion1

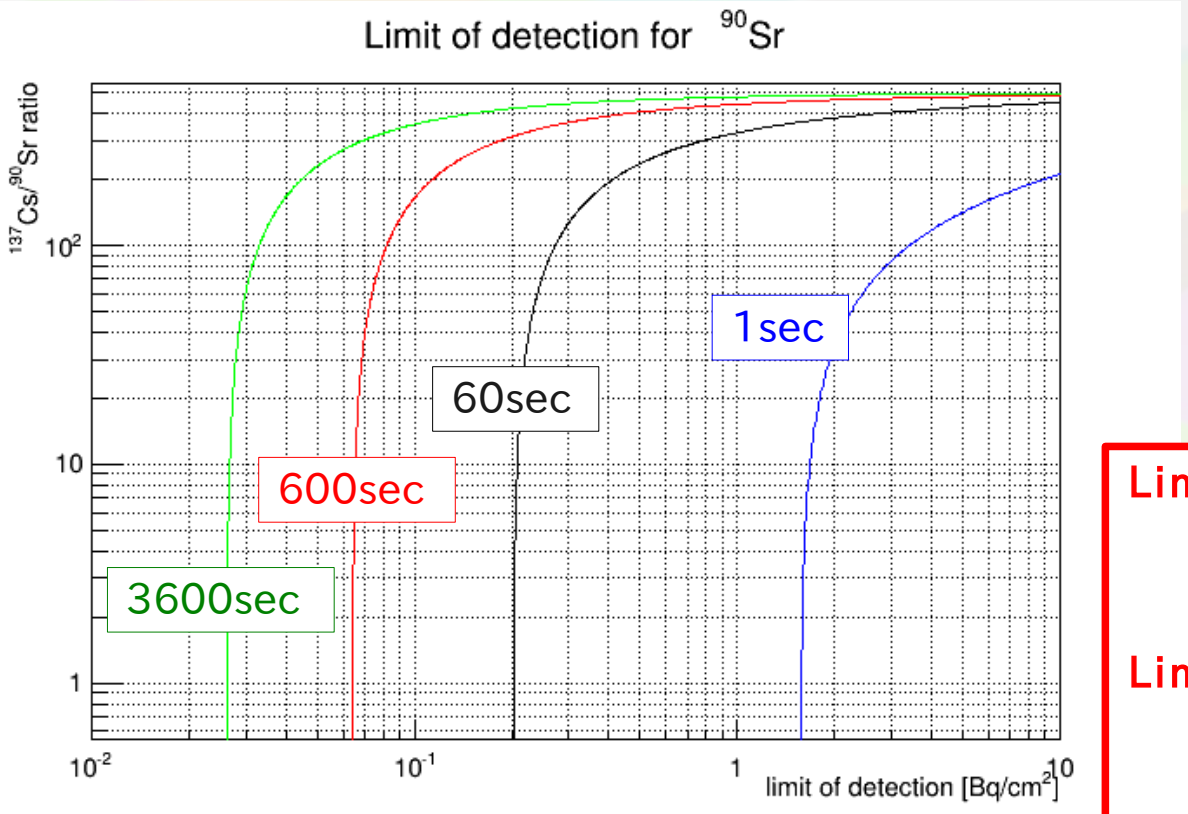
Prototype

Effective area :	30 x 10 cm^2
^{90}Sr sensitivity :	2.8 x 10^{-3} Hz/Bq
^{137}Cs sensitivity:	6 x 10^{-6} Hz/Bq
BG noise ratio	0.28 Hz
Sr/Cs ratio:	500
Position uniformity :	96%

$$N_{Sr} = aSxt + ct$$
$$N_{Cs} = bkSxt + ct$$
$$N_{Sr} > N_{Cs} + 2.58\sqrt{N_{Cs}}$$

Reliability of 99% or more

N_{Sr} : Number of counts for Sr
N_{Cs} : Number of counts for Cs
a : Sr sensitivity $[Hz/Bq]$
b : Cs sensitivity $[Hz/Bq]$
c : Noise ratio $[Hz]$
S : Effective area $[cm^2]$
k : Sr/Cs ratio
t : time of measurement $[sec]$
x : lomit of detection $[Bq/cm^2]$



Limit of detection : ～0.3 [Bq/cm²]

Monitoring time : 60 sec
Allowable ratio of Cs/Sr : 100

Limit of detection : ～0.08 [Bq/cm²]

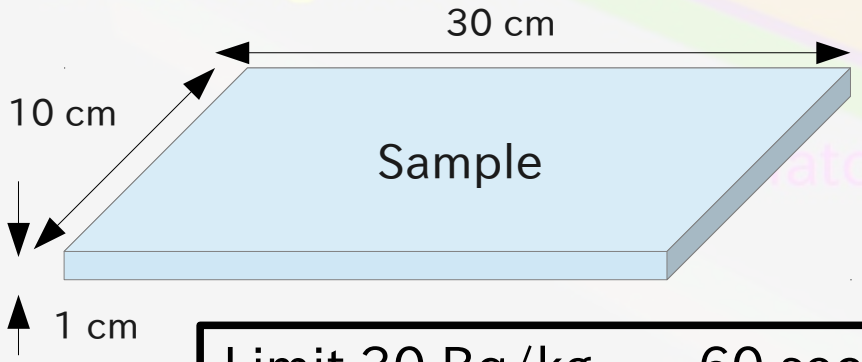
Monitoring time : 600 sec
Allowable ratio of Cs/Sr : 100

Discussion2

Limit of detection:	**0.3 [Bq/cm²]**
Monitoring time:	60 sec
Allowable ratio of Sr/Cs:	100
Limit of detection:	**0.08 [Bq/cm²]**
Monitoring time:	600 sec
Allowable ratio of Sr/Cs:	100

New reference value: 10 Bq/kg of ^{90}Sr in foods
by Ministry of Health, Labour and Welfare in Japan.

Beta-ray is measured only the surface of the sample.



Improving the performance

(1) PMT logic optimization
(2) Extending effective area
...and so on.

Limit 30 Bq/kg … 60 sec
Limit 8 Bq/kg … 600 sec

The limit of detection satisfies the reference value with monitoring of 10 minutes.

Summary

We performd production and measurement of prototype.

Effective area:	30 x 10 cm^2
^{90}Sr sensitivity:	2.8 x 10^{-3} Hz/Bq
^{137}Cs sensitivity:	6 x 10^{-6} Hz/Bq
BG noise ratio:	0.28 Hz
Sr/Cs ratio:	500
Position uniformity:	96%

Limit of detection : 8 [Bq/kg]

Sample size:	30 x 10 x 1 cm^3
Monitoring time:	600 sec
Allowable ratio of Sr/Cs:	100

Reliability of 99% or more

The counter has a limit of detection of satisfies for the reference value.

Further improve the sensitivity of ^{90}Sr and a practical trial production run is expected.

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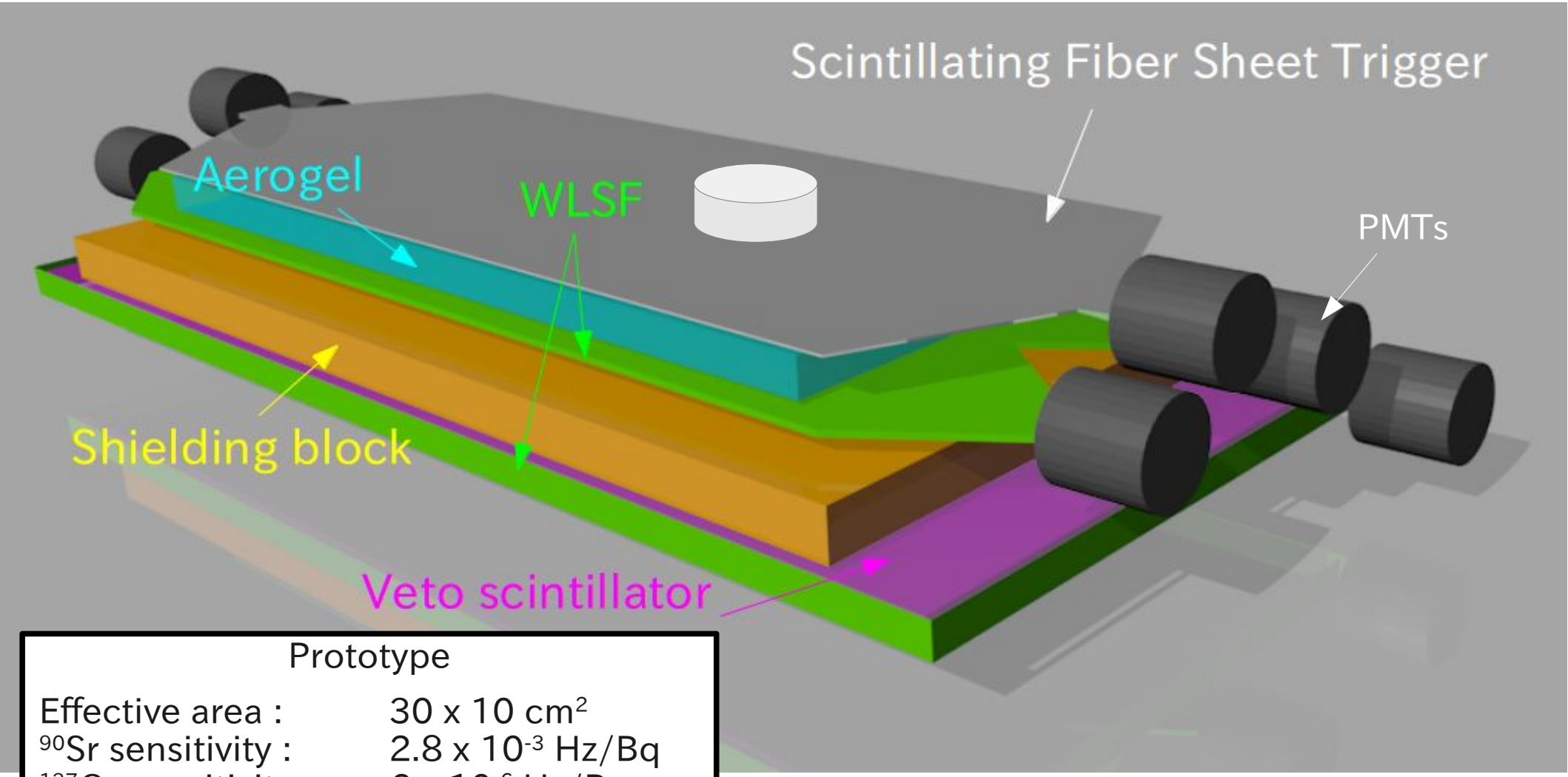


Prototype	
Effective area :	30 x 10 cm^2
^{90}Sr sensitivity :	2.8 x 10^{-3} Hz/Bq
^{137}Cs sensitivity:	6 x 10^{-6} Hz/Bq
BG noise ratio	0.28 Hz
Sr/Cs ratio:	500
Position uniformity :	96%

Thank you for your attention

Back Up

Cherenkov counter for $^{90}Sr/^{137}Cs$ with aerogel radiator

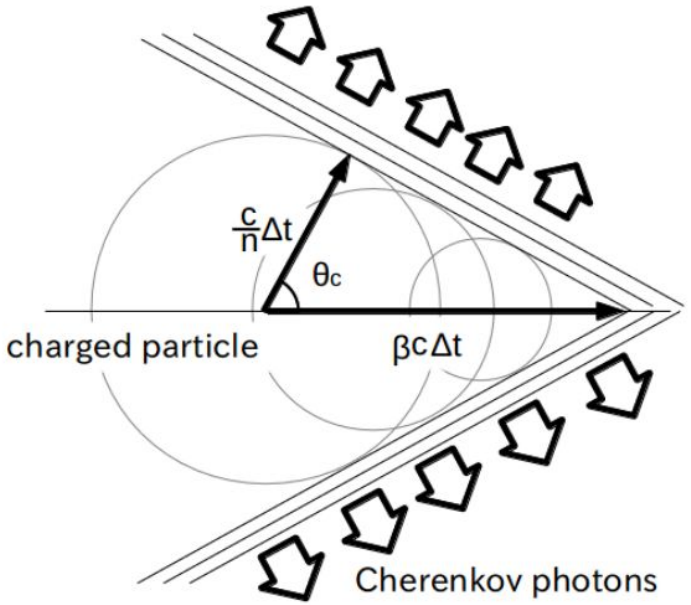
$^{90}Sr/^{90}Y$

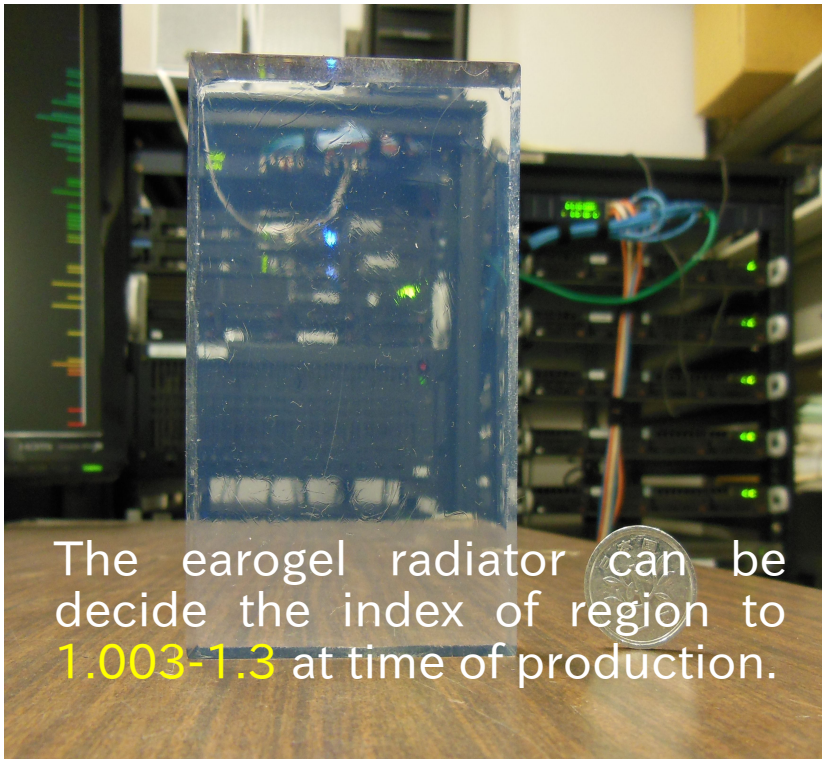
β-ray: 0.55MeV
β-ray: 2.28MeV

^{137}Cs

95%
β-ray: 0.51MeV
γ-ray: 0.66MeV
5%
β-ray: 1.17MeV

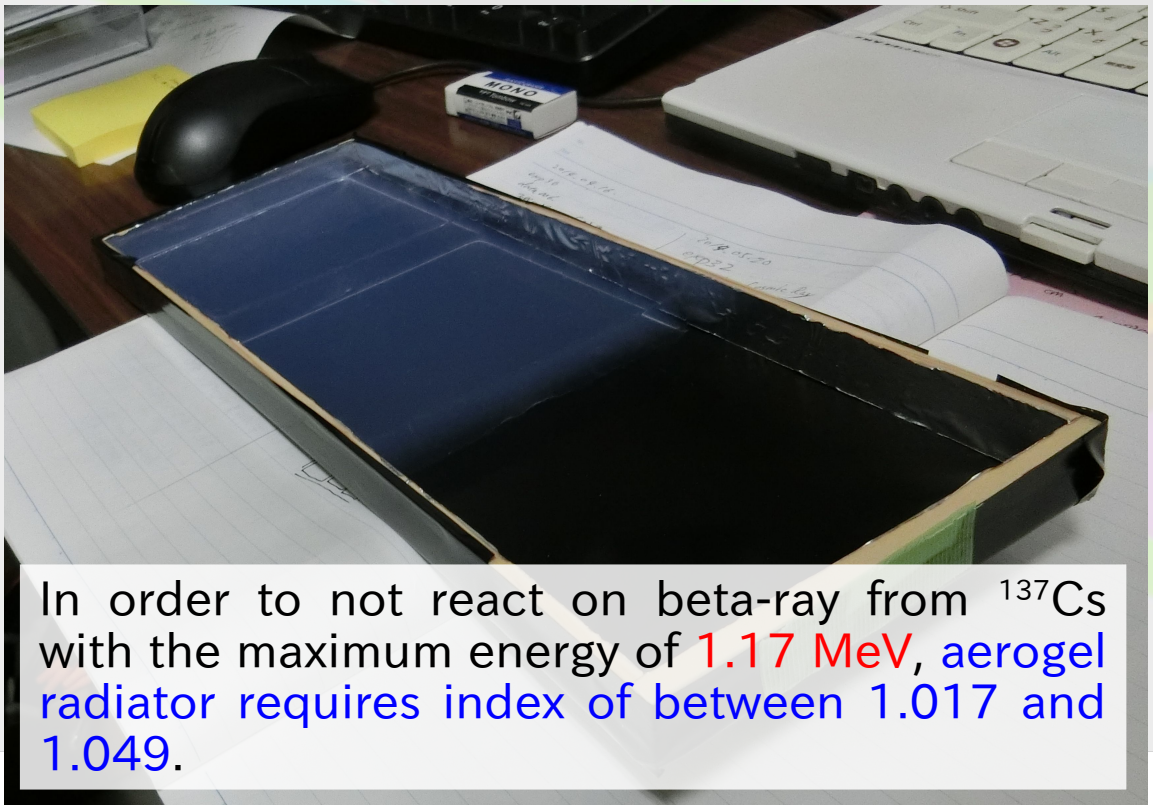
The maximum energy of beta-ray from ^{137}Cs as threshold is 1.17 MeV. It mean a radiator requires index of less than 1.049 and 1.017 or more.





Development of ^{90}Sr Counter

Aerogel



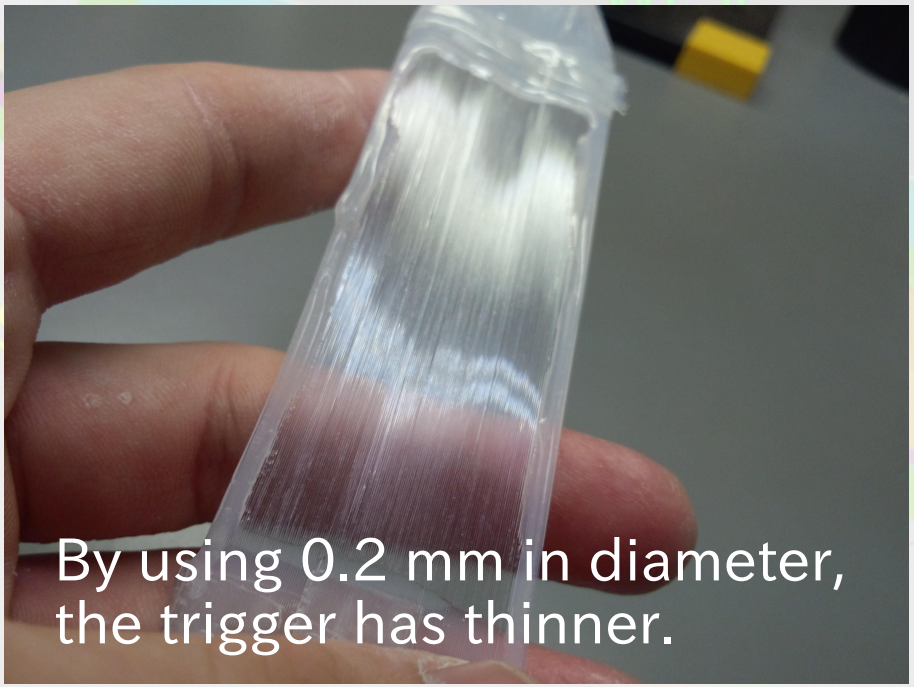
In order to not react on beta-ray from ^{137}Cs with the maximum energy of 1.17 MeV, aerogel radiator requires index of between 1.017 and 1.049.

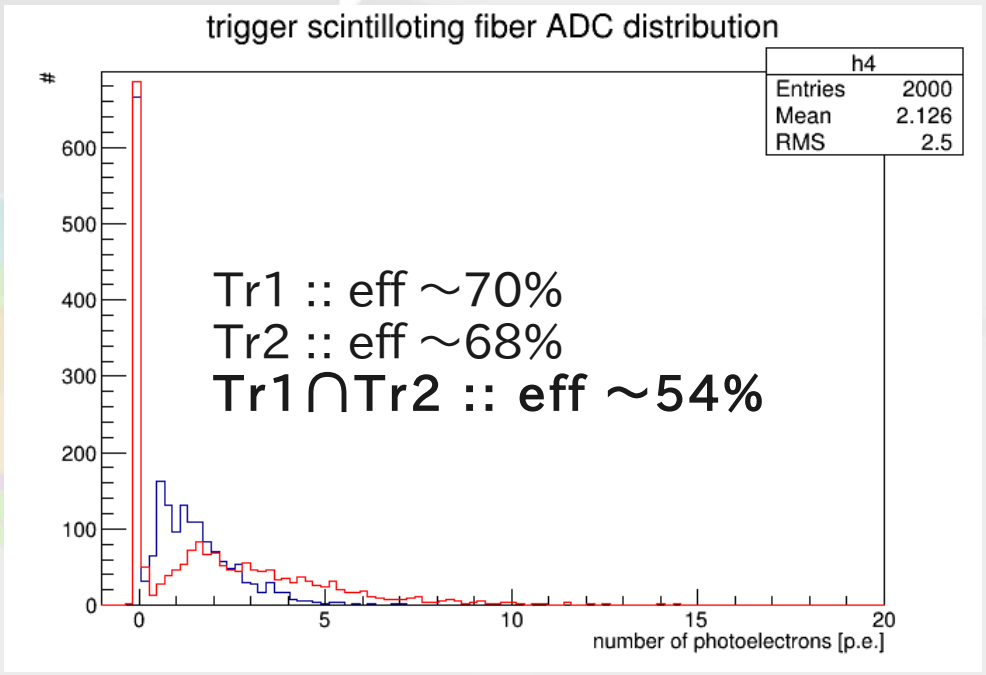
MEC1 left-handed (LAD-C) notation PS mold size: 96.25 mm solvogel synthesis: 2014/4/27 S.C.D. complition: 2014/5/15

ID			MEC1-1a	MEC1-1b	MEC1-1c
ref.index @405nm (absolute)			1.0450	1.0450	1.0449
trans.length @400nm		[mm]	46.4	45.4	46.1
size	dimension	[mm]	93.5	93.5	93.5
	thickness		10.1	10.3	10.1
	volume	[cm^3]	88	90	89
density		[g/cm^3]	0.152	0.152	0.153
k @405nm		[cm^3/g]	0.296	0.296	0.293
total error of ref.index			0.0011	0.0009	0.0009
resolution of measurement	error ref.index @405nm		0.0003	0.0004	0.0003
			0.0011	0.0008	0.0008
	trans.length	[mm]	1.4	1.3	1.4
	volume	[cm^3]	2	2	2
	density	[g/cm^3]	0.004	0.004	0.004
	spot radius @405nm	[mm]	4	3	3
aerogel-screen distance		[mm]	1823	1823	1823
spot shift (right) @405nm	corner α	[mm]	168.5	165.5	165.5
	corner β		166.0	168.0	166.0
	corner γ		166.5	169.0	167.0
	corner δ		168.5	166.0	168.5
transmittance @400nm		[%T]	80.5	79.8	80.3
demension (detail)	A	[mm]	93.50	93.50	93.50
	B		93.50	93.50	93.50
	C		93.50	93.50	93.50
	D		93.50	93.50	93.50
long.shrink.ratio			0.971	0.971	0.971
thickness (detail)	a	[mm]	10.00	10.25	10.25
	b		10.25	10.00	10.00
	c		10.00	10.25	10.00
	d		10.00	10.50	10.25
weight		[g]	13.37	13.63	13.55
crack			free	free	free
remark					

Development of ^{90}Sr Counter

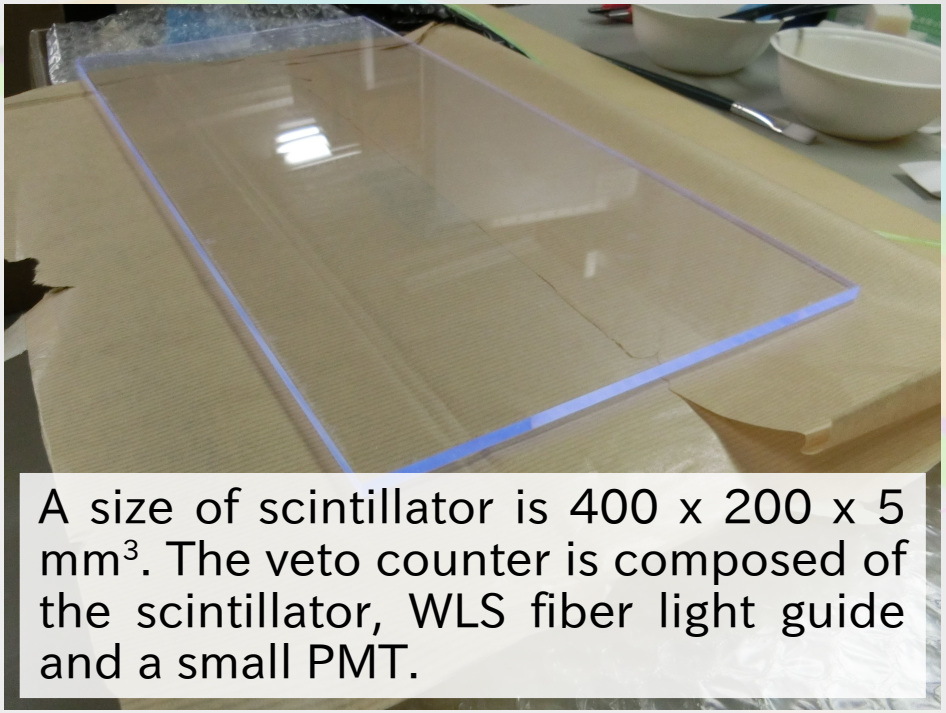
Scintillating Fiber trigger



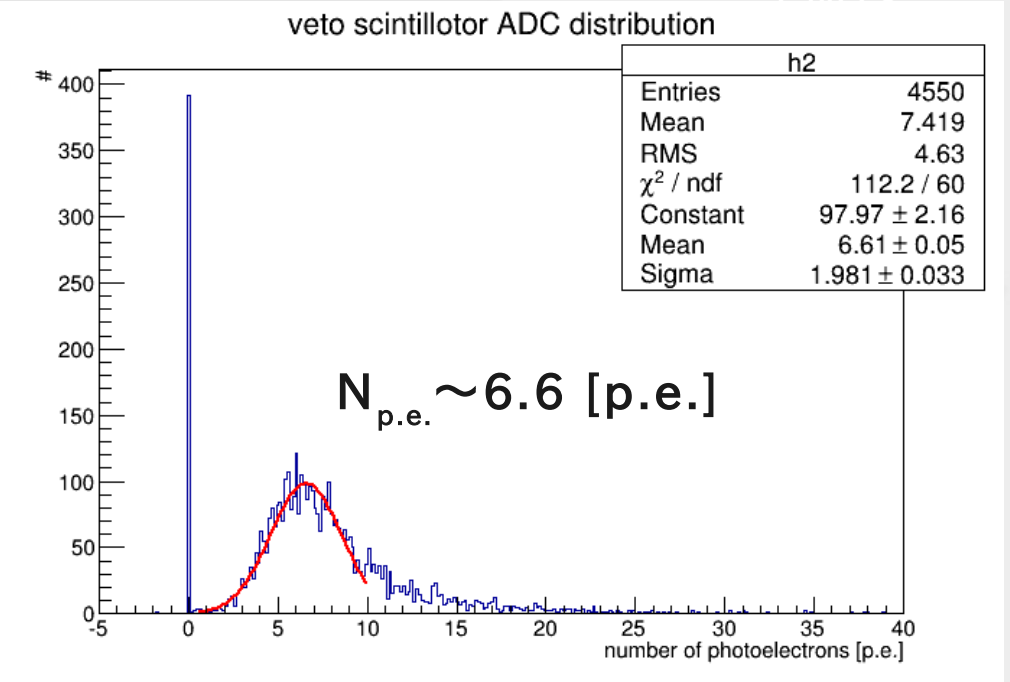


Development of ^{90}Sr Counter

Veto scintillator



A size of scintillator is 400 x 200 x 5 mm^3. The veto counter is composed of the scintillator, WLS fiber light guide and a small PMT.



Calculate of maximum range for β-ray

maximum range for β-ray

$R=0.542E/MeV - 0.133\ [g/cm^2]\ (E>0.8MeV)$

$R=0.407(E/MeV)^{1.38}\ [g/cm^2]\ (0.15<E<0.8MeV)$

E:電子の運動エネルギー[MeV]

Density of aluminum

$\rho = 13.4g/5/5/0.21$

$= 2.55[g/cm^3]$

calculate

$R_1=0.542*1.174-0.113=0.503$

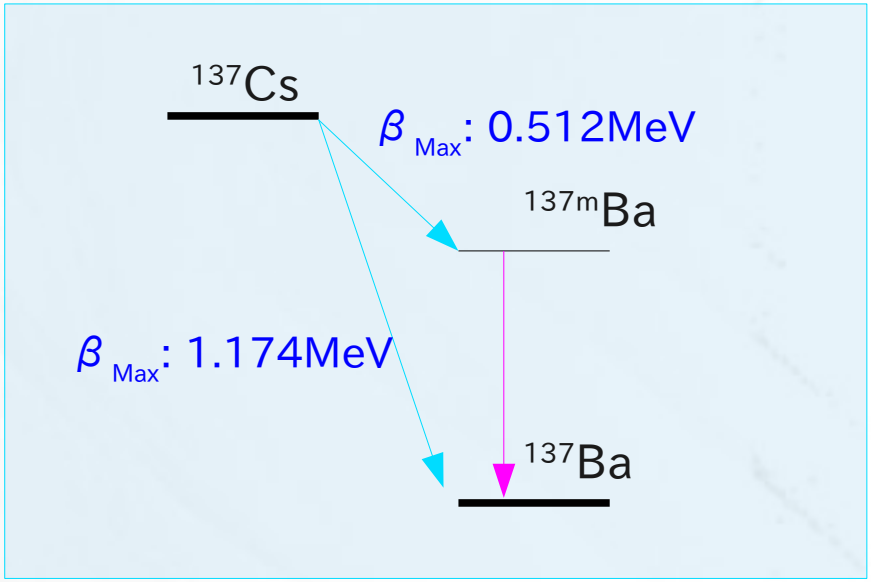
$R_2=0.497*0.512^{1.38}=0.162$

$L=R/\rho$

$L_1=0.197cm$

$L_2=0.0635cm$

maximum range for β-ray from ^{137}Cs is 2mm.



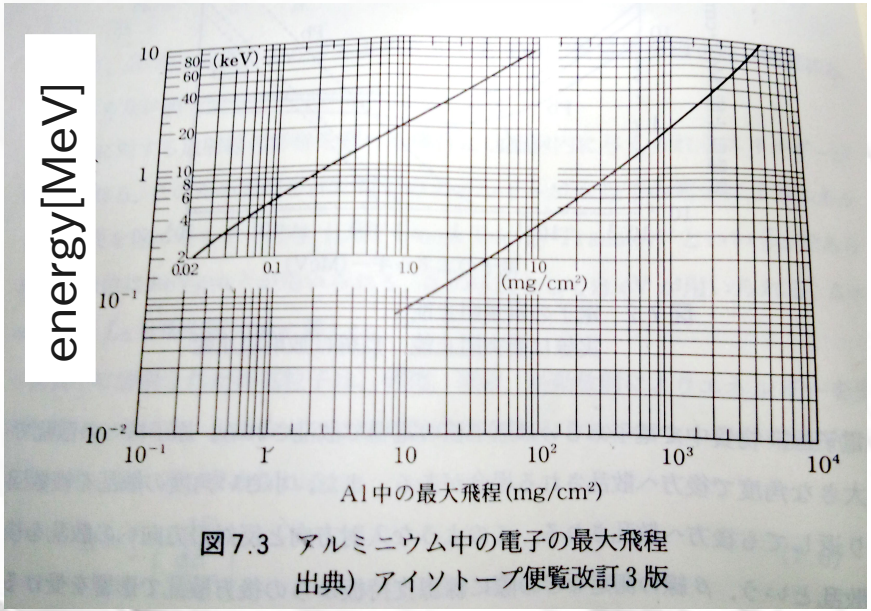


図7.3 アルミニウム中の電子の最大飛程
出典) アイソトープ便覧改訂3版