Development of Scintillator Readout System with MPPC for Potable Compact Gamma-ray Spectrometer

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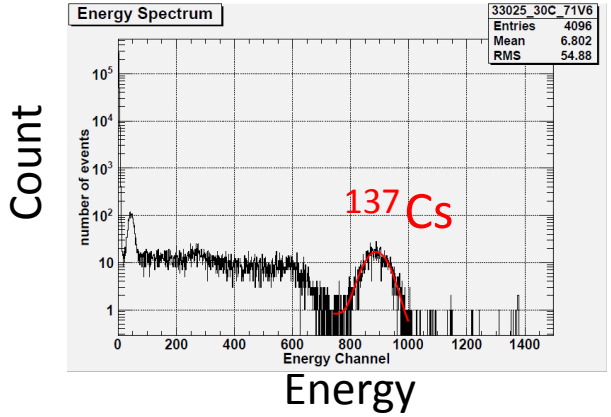
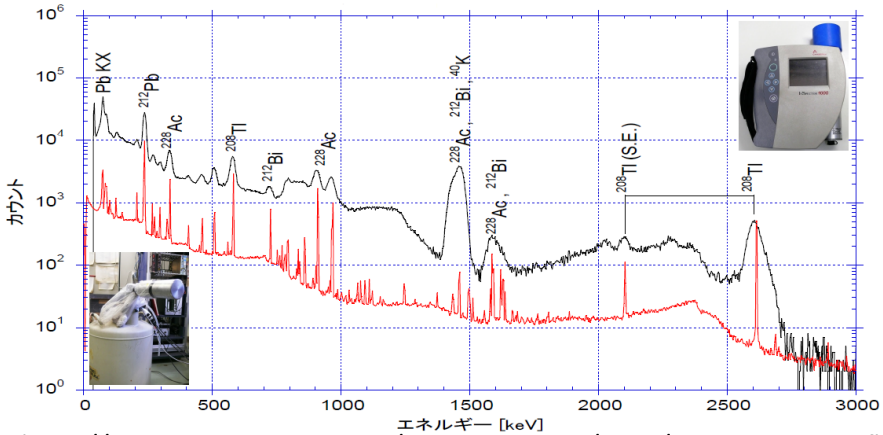
Potable Radiation Detector

After the Fukushima Daiichi nuclear accident, there are many opportunities to measure and identify the radioactive isotopes from the environment.
=> Spectral information is important for potable radiation detectors.

Detector	Counting	Spectrum	Cost
Geiger Counter (Gas)	Yes	No	Cheap
Scintillator	**Yes**	**Yes**	**Normal**
Semiconductor	Yes	Excellent	Expensive





(http://anp.nucl.nagoya-u.ac.jp/cloud_chamber/2009/BG_radiation.pdf)

We are developing a relatively cheap and portable detector which can also measure energy spectra, with using CsI (Tl) scintillator.

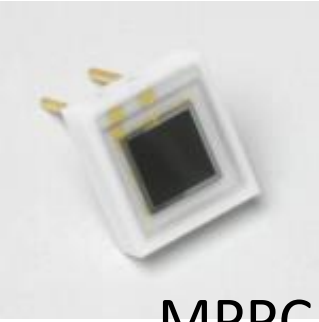
Photo-Detector for Scintillator

Photo-detector	Size	High Voltage	Amplification Factor	Operation Temperature
Photomultitube	~cm	~1 kV	10^7	No strict constraint
Avalanche Photodiode	<cm	Several 100 V	50-100	< 0 ℃
Si-PM Multi-Pixel Photon Counter (MPPC)	**<cm**	**~70 V (old) ~50 V (new)**	**10^6**	**No strict constraint (Need stability)**

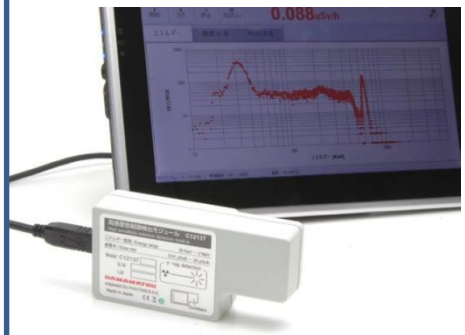
We selected MPPC, since it is small and can be operated with lower high voltage under the room temperature (also cheap).

CsI (Tl)

+



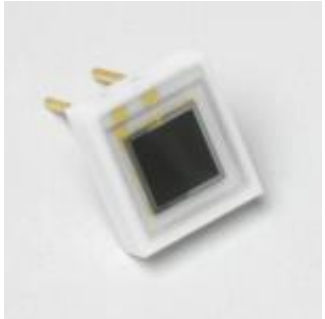
MPPC



Hamamatsu C12137

Selection of MPPC (1)

Pixel Size (um)	Pixel Number (/mm2)	Aperture ratio (%)
25	1600	30(old)-50(new)
50	400	60(old)-75(new)
100	100	~80



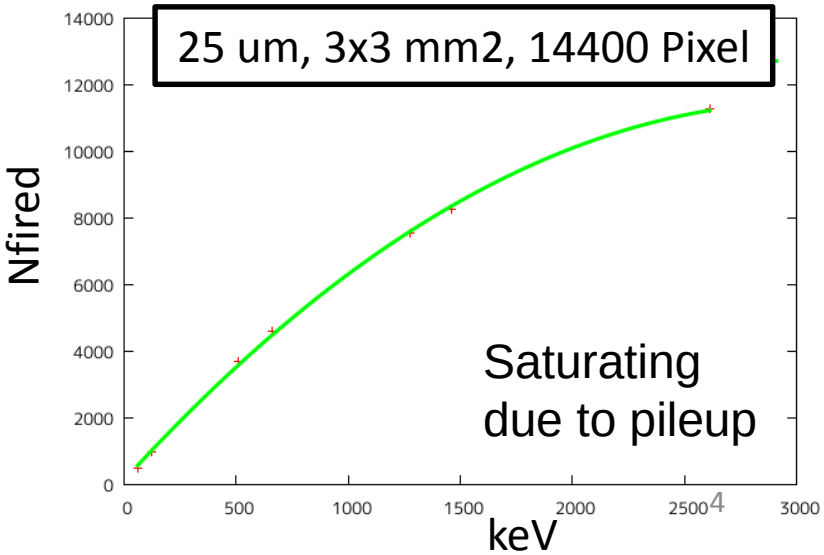
- Detector size: 1, 3, 6, 12 mm2

- To obtain better energy resolution, MPPC needs to catch more scintillation photons. => **larger aperture ratio**
- MPPC is operated as Geiger mode, and output the same pulse height if there are several photons detected by one pixel (pile-up). => **more pixel number**

#CsI(Tl) emits 56000 photons/MeV.

$$\mathrm{Nfired} = \mathrm{Ntotal} \times \left[1 - \exp\left(\frac{-\mathrm{Nphoton} \times \mathrm{PDE}}{\mathrm{Ntotal}}\right)\right]$$

Nfired: Num of pixels detecting photons
Ntotal: Num of total pixels
Nphoton: Num of input photons
PDE: Detection efficiency x Aperture ratio



Selection of MPPC (2)

Since
- decay time of CsI(Tl) emission is ~1000ns
- MPPC recovery time is several – several 10s ns,

we chose **S10985-050C (6x6mm^2, 50um pixel size, 14400 pixels)**

See T. Nakaoka's poster about plastic scintillators (decay time: ~ns, less scintillation photons.)

MPPC: currently available

56000photons

Aperture ratio [%] (pixel size [um])

Ntotal	30.8 (25)	61.5 (50)	78.5 (100)	100
100	0.007247	0.00363	0.002843	0.002232
400	0.028989	0.014518	0.011374	0.008929
900	0.065225	0.032666	0.025591	0.020089
1600	0.115935	0.058072	0.045496	0.035714
3600	0.255252	0.1306	0.10236	0.080357
14400	0.643302	0.445512	0.373853	0.307108
57600	0.88924	0.794811	0.748418	0.695024

10000photons

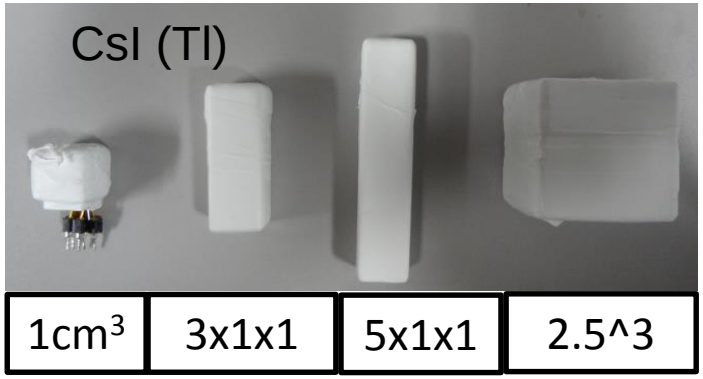
	30.8 (25)	61.5 (50)	78.5 (100)	100
100	0.040584	0.020325	0.015924	0.0125
400	0.161995	0.0813	0.063694	0.05
900	0.341622	0.182154	0.143178	0.112484
1600	0.510142	0.310182	0.249747	0.198652
3600	0.724134	0.545155	0.473078	0.401234
14400	0.919122	0.847068	0.810468	0.767244
57600	0.978913	0.958482	0.947414	0.933662

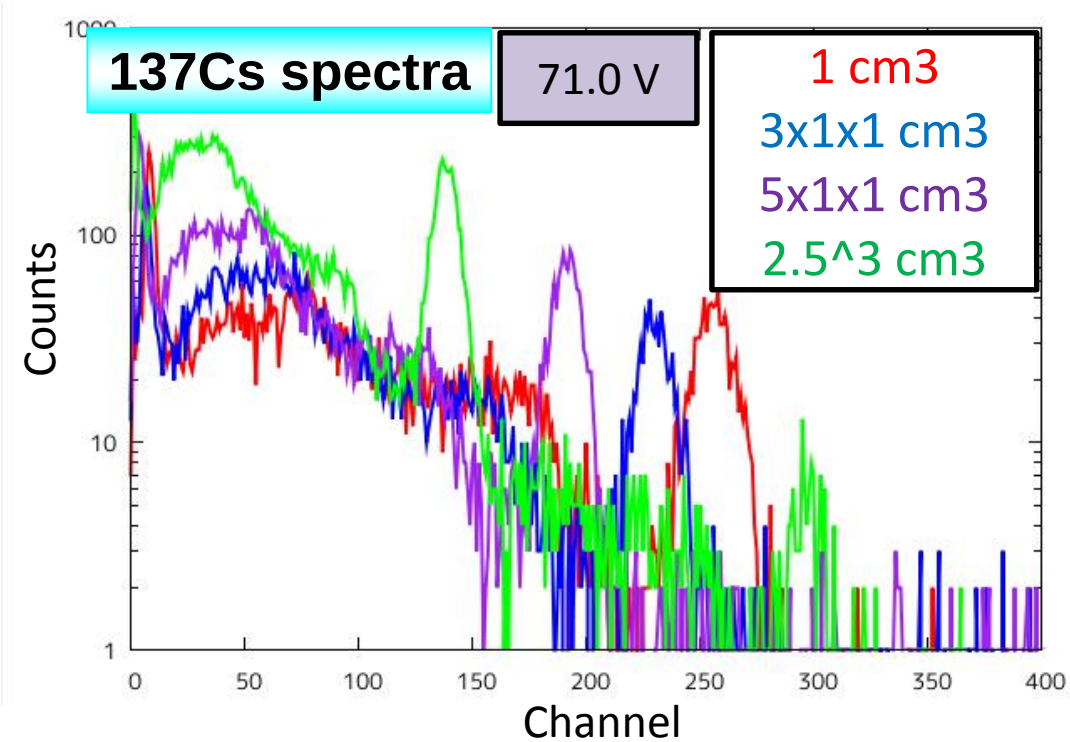
1000photons

	30.8 (25)	61.5 (50)	78.5 (100)	100
100	0.371309	0.201768	0.158937	0.124958
400	0.74659	0.575372	0.50443	0.432332
900	0.874793	0.770348	0.719871	0.662499
1600	0.926805	0.860869	0.827092	0.786939
3600	0.966545	0.934676	0.917636	0.896682
14400	0.991493	0.98311	0.978508	0.97273
57600	0.997864	0.995741	0.994568	0.993088

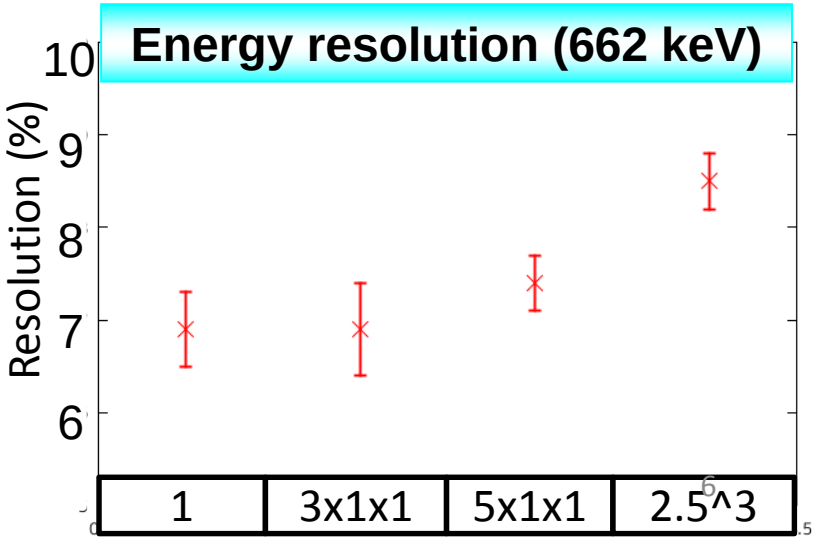
Selection of CsI (Tl) Size

It is demanded to separate two lines of 605 keV(134Cs) and 662 keV(137Cs) => **ΔE<9%@662 keV.**





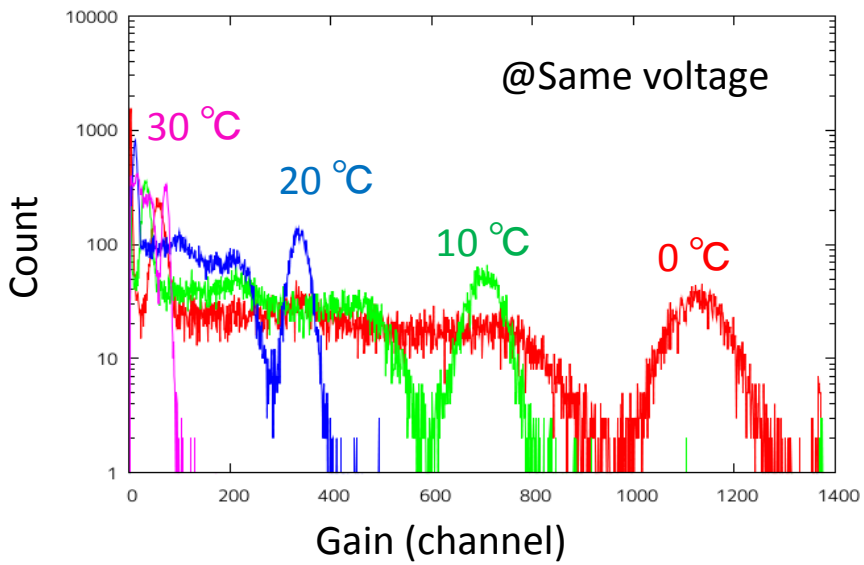
We tested 4 sizes of CsI (Tl).
=> Bigger one requires less exposure.
Less scintillation photons are collected.

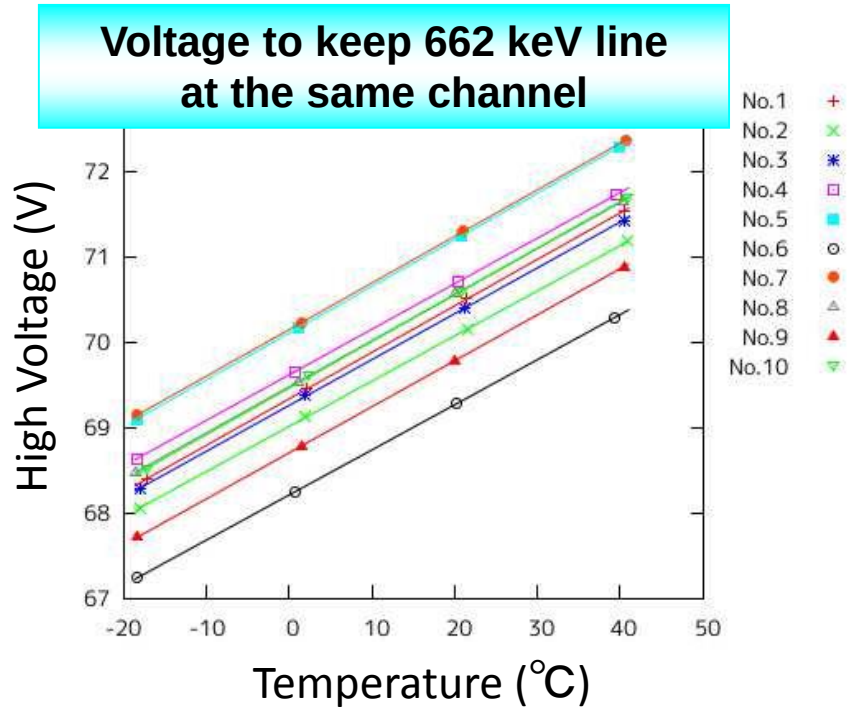


All the tested pieces pass the requirements, and **we prepared two modules with 3x1x1cm³ or 1-inch cubic.**

Temperature Dependence

MPPC (and CsI (Tl)) gain changes largely depending on temperature.





We measured 10 sets of MPPC(S10985-050C) + 1-inch CsI(Tl), with changing the high voltage, to keep the same pulse height.

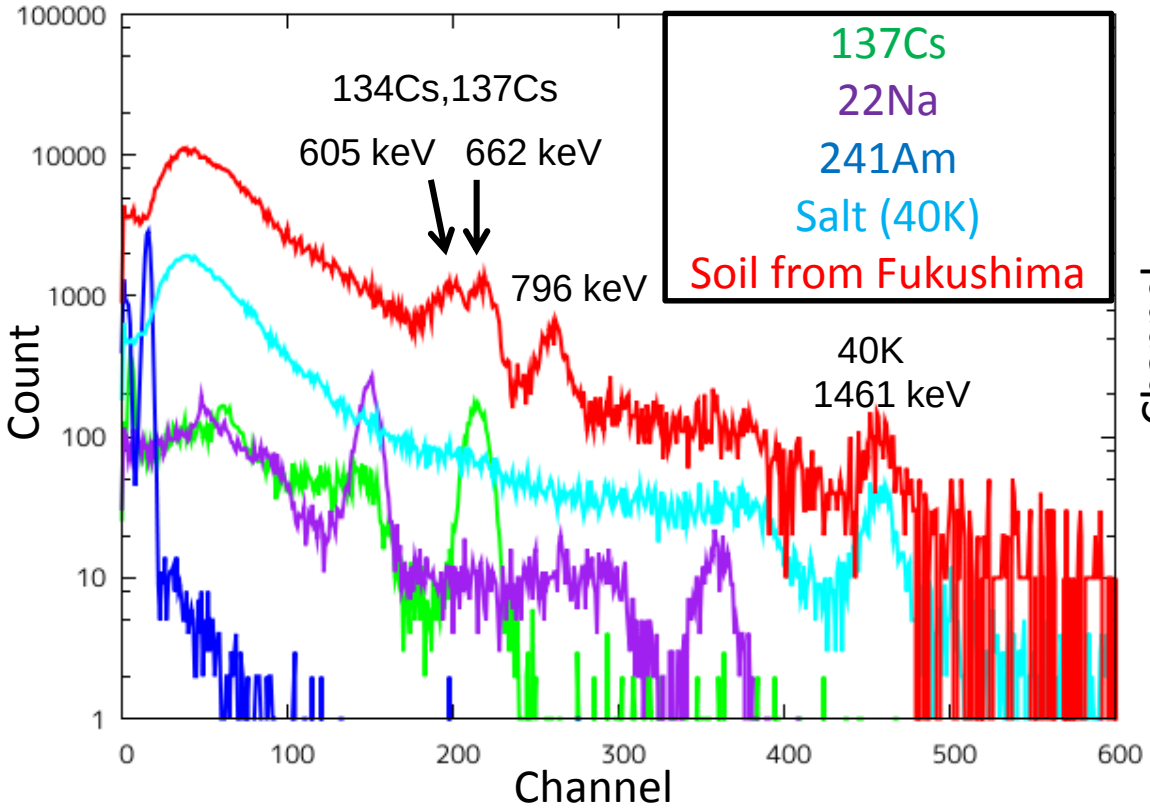
=> **Temperature dependency is similar (at least) among these 10 units.**

- Assuming the same slope, the energy resolution does not become worse than 9%.

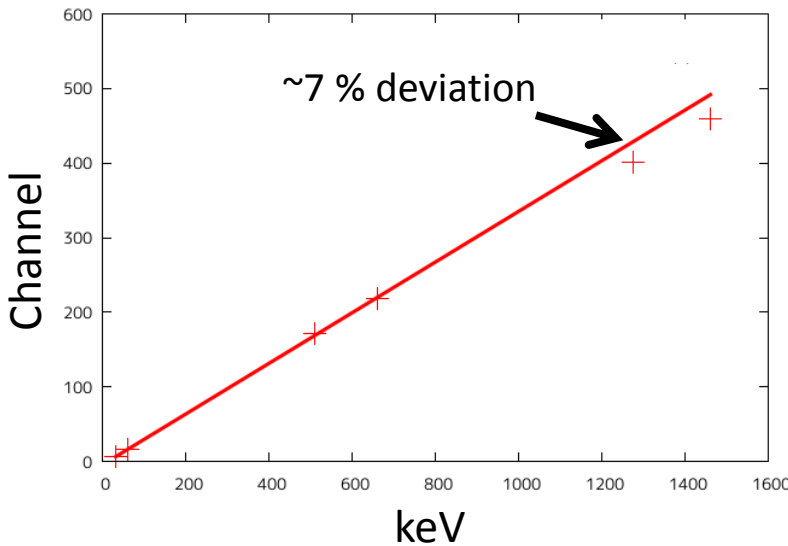
- Only the offset changes unit by unit.

=> Our detector includes feedback circuit of high voltage with temperature monitor, and temperature dependency is automatically corrected.

MPPC (S10985-050C)+CsI (3x1x1 cm^3)



20 ℃, 71V



JAEA facility @2014/Feb.

- Two peaks of 134Cs (606 keV) and 137Cs (662 keV) are clearly separated.
- Non linearity caused by pile-up is ~7% above 1 MeV.
  <= This deviation can be adjusted in digital circuit when displaying the spectrum.

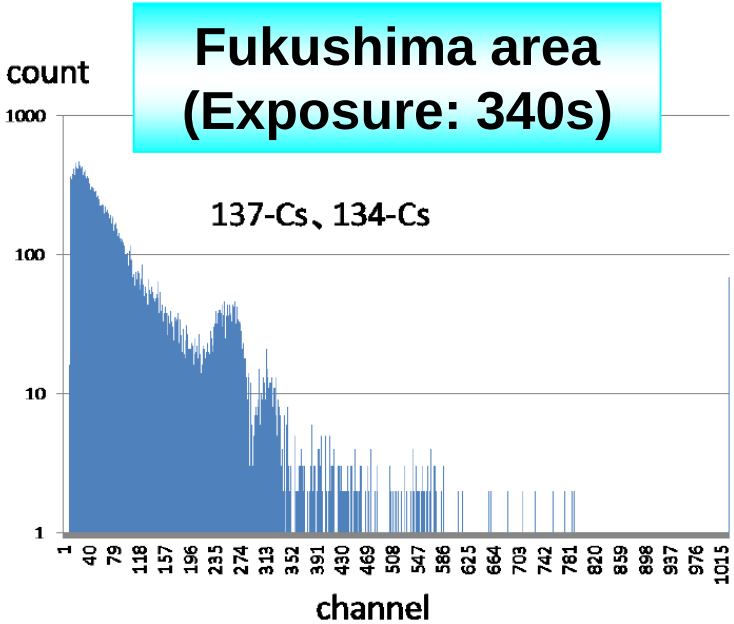
- We calibrated the conversion factor from counts/s to uSv/h at JAEA (Japan Atomic Energy Agency).

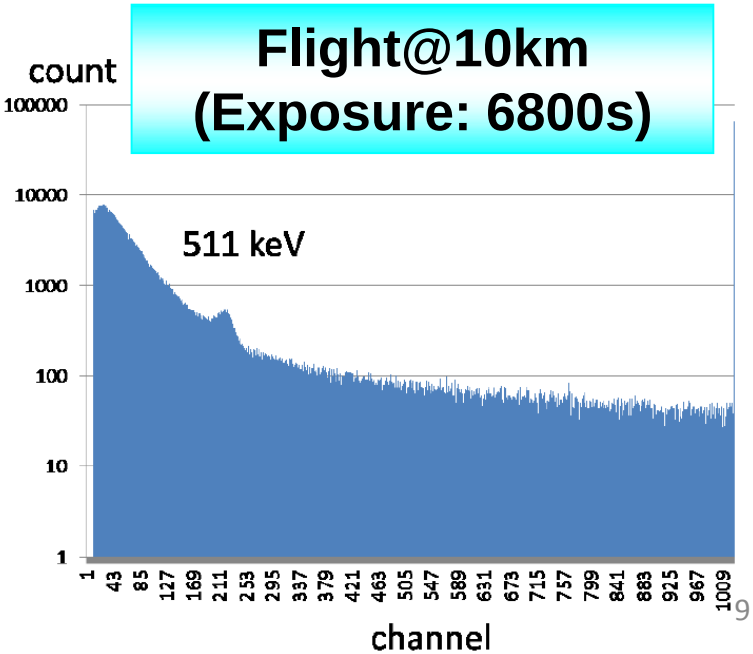
T-GMK2-S (TAC Co. Ltd.)

http://www.tacinc.jp/T-GMK2-S/index.html

Portable gamma-ray spectrometer

- MPPC + CsI(Tl) 3x1x1 cm^3
- Display and circuit size:
  W40 x H130 x D25 mm
- Sensor size: Φ32.4 x 86.5 mm
- **It can display the spectrum.**





Summary

- We have developed the portable gamma-ray spectrometer with MPPC + CsI (Tl), which has the display to show the real-time spectrum.

- After selecting the proper sizes of MPPC and CsI (Tl), two peaks of 134Cs and 137Cs can be separated in the spectrum.

- The temperature dependence of MPPC + CsI (Tl) was measured, and the feedback circuit of high voltage with temperature monitor is implemented.

- The detector was calibrated at JAEA and the conversion factor from counts/s to uSv/h was obtained.

- We will upgrade MPPC to the recent S13360 series (and with a bigger display).

CsI (Tl) Scintillator

	Density (g/cm3)	Light yield (photons/MeV)	Emission wavelength (nm)
CsI (Tl)	4.53	56000	550

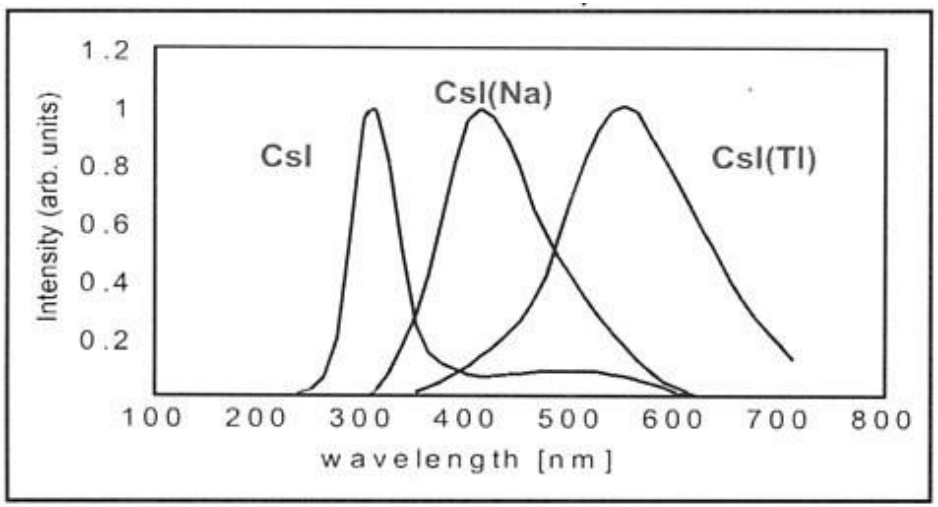


Fig. 3.2 ***Emission spectra of CsI, CsI(Na) and CsI(Tl) scaled on maximum emission intensity. Also a typical quantum efficiency curve of a bialkali photocathode is shown.***

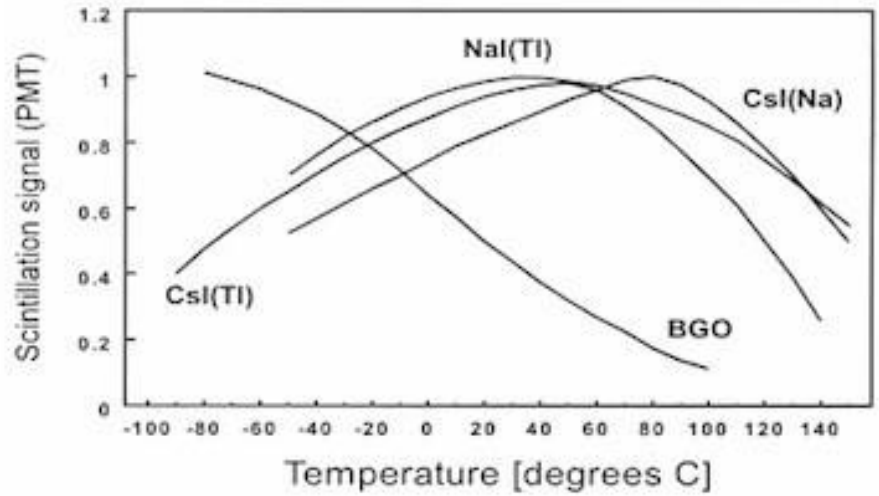


Fig. 3.3 ***Temperature dependence of the scintillation yield of NaI(Tl), CsI(Na), CsI(Tl) and BGO.***

(scionix)