Development of InP solid state and liquid scintillator containing metal complex of pp/7Be solar neutrinos and neutrinoless double beta decay

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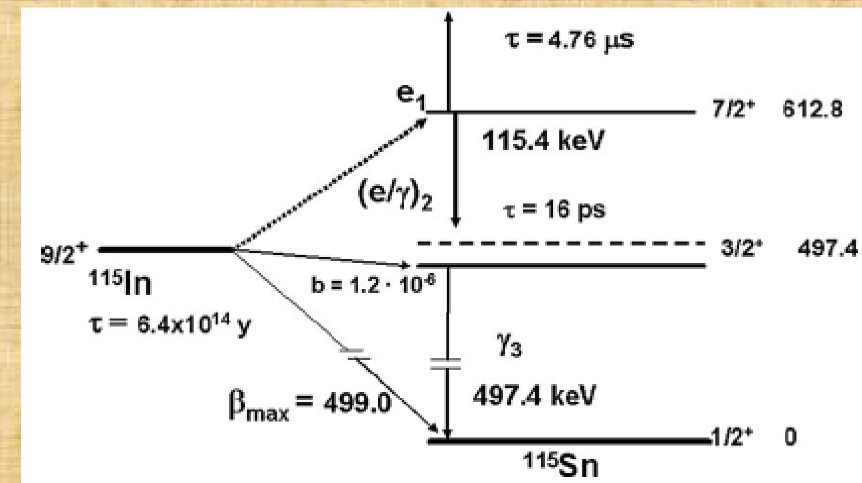
Capture of low energy solar neutrinos by ^{115}In

R.S.Raghavan Phs.Rev.Lett37(1976)259



Nuclear Physics A 748 (2005) 333-347

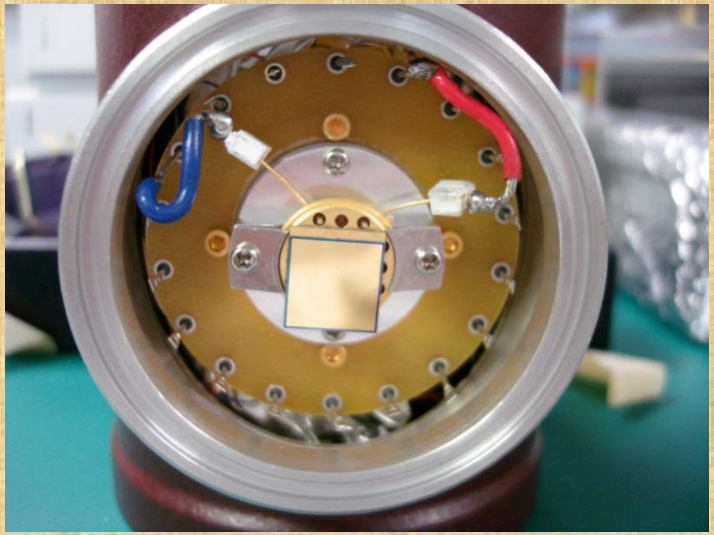
^{115}In + $\nu_e \rightarrow$ ^{115}Sn* + e$^-$
^{115}Sn*(4.76μs) $\rightarrow$ ^{115}Sn +
γ_1(115keV) + γ_2(497keV)

- Advantage
  - large cross section (~640SNU)
  - direct counting for solar neutrinos
  - sensitive to low energy region ($E_\nu \geqq$ 125keV)
  - energy measurement ($E_e = E_\nu -$ 125keV)
  - triple fold coincidence to extract neutrino signal from huge BG ($e_1 + \gamma_2 + \gamma_3$)
- Disadvantage
  - natural β-decay of ^{115}In ($\tau_{1/2} = 4.4 \times 10^{14}$ yr , Ee≧498keV)
  - possible BG due to correlated coincidence by radiative Bremsstrahlung

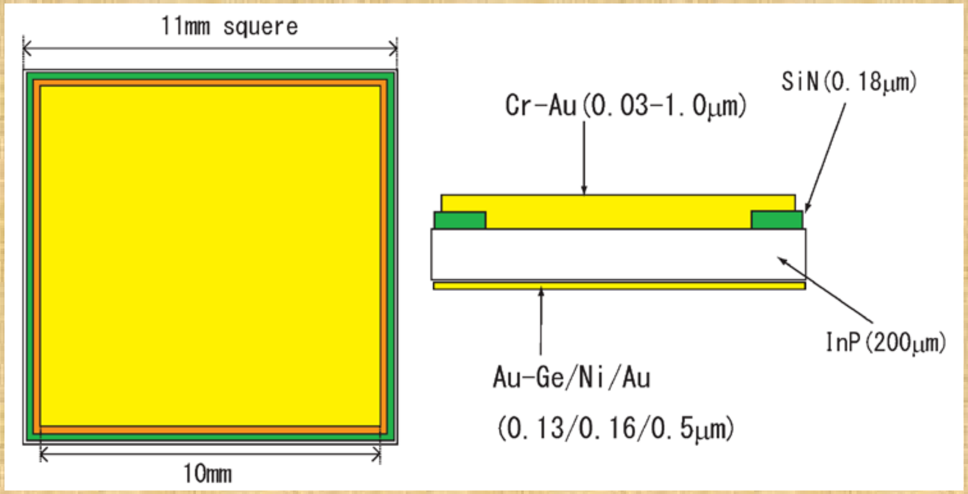
Goal

1. Good energy resolution : 10%(FWHM)
2. Fine segmentation (10^4-10^5)
3. High efficiency γ detection

Semi-insulating InP cell detector



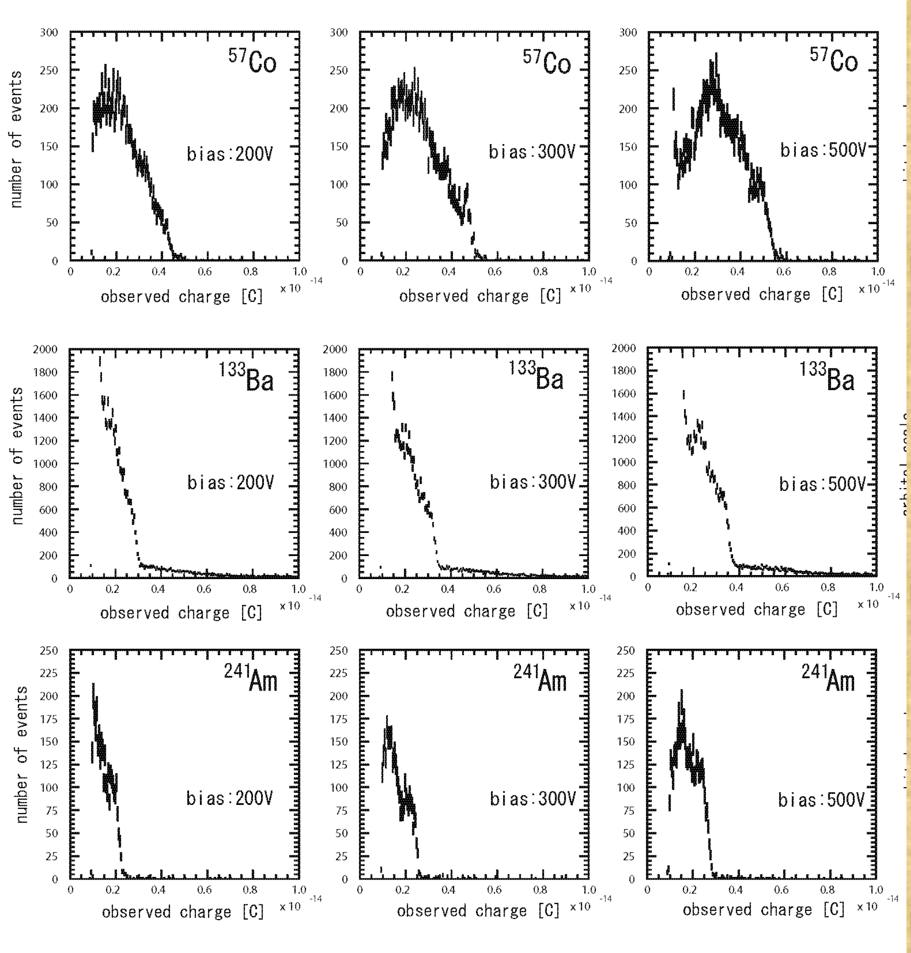
mounted in vacuum dewar



- Semi-insulating InP VCZ substrate by Sumitomo Electric Industrials
- Assembled by Hamamatsu Photonics
- Operation at -79degree

Surface size:
・10mm × 10mm × 0.2mm
・6mm × 6mm × 0.2/0.23/0.28/0.45mm
Electrode :
・ Ohmic contact
・ evaporated Au/Cr base metal
・ Insulator (SiN) to avoid leak current

Gamma ray spectrum observed by InP

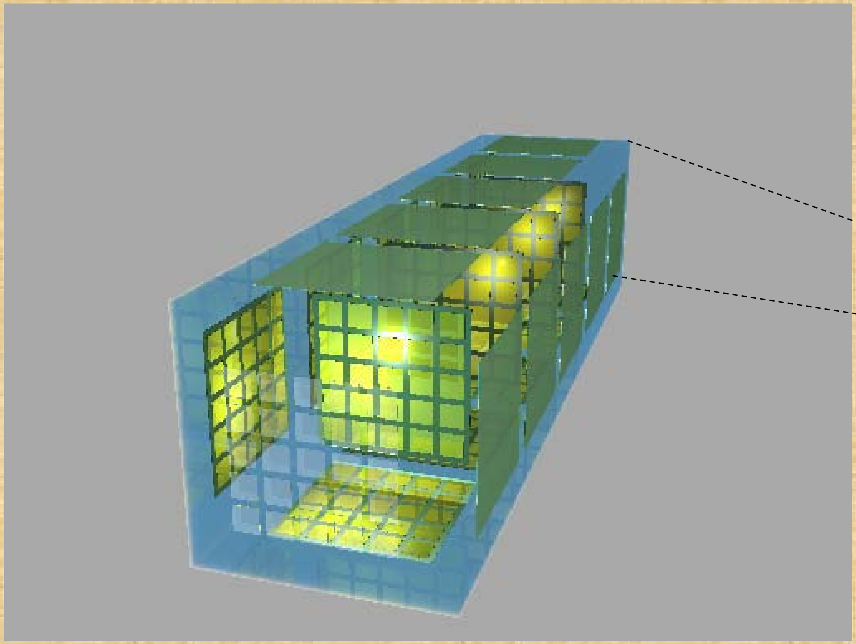


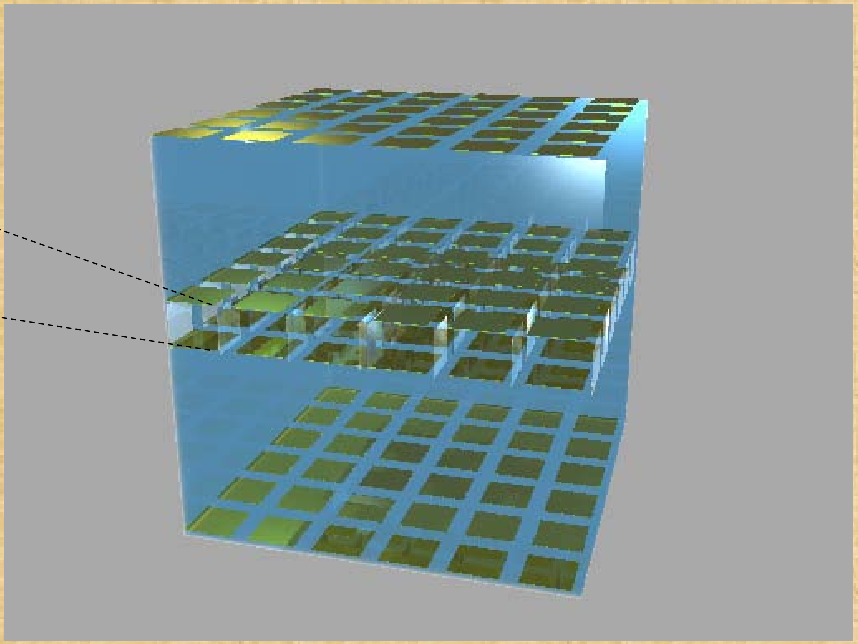
- Measured clear photo-peak , but two peak structure
- Major peak: induced charge collection (L_{ed}~200μm L_{he} ~ 30μm)
- Small peak: full charge collection
- Energy of electron-hole pair production :3.5eV
- Energy resolution : 25%@122keV

IPNOS phase-I experiment for pp/7Be Solar ν experiment

InP multi-pixel detector inside of Liquid Xenon (Lxe).

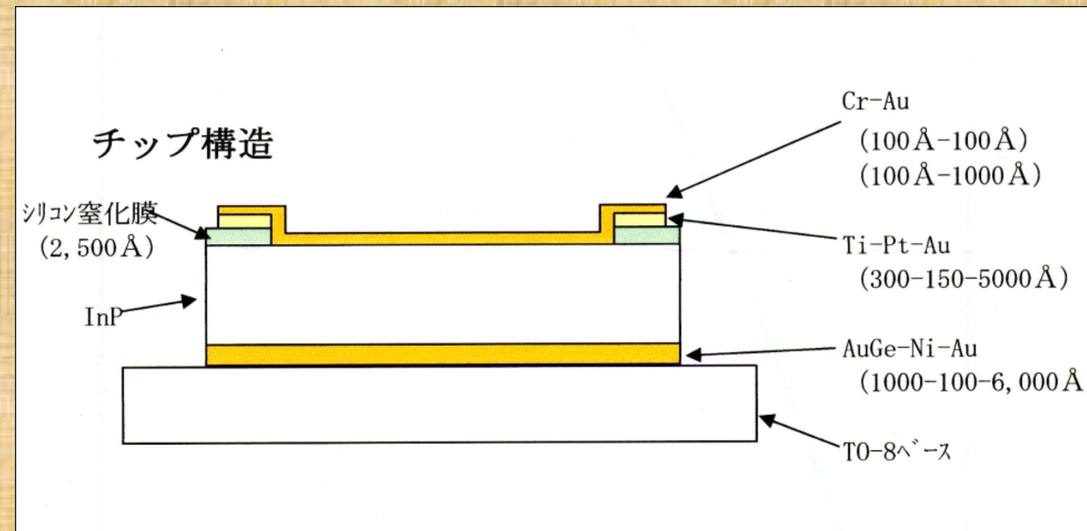
30cm cubic chamber (like XMASS 100kg prototype) includes ~10kg InP detector

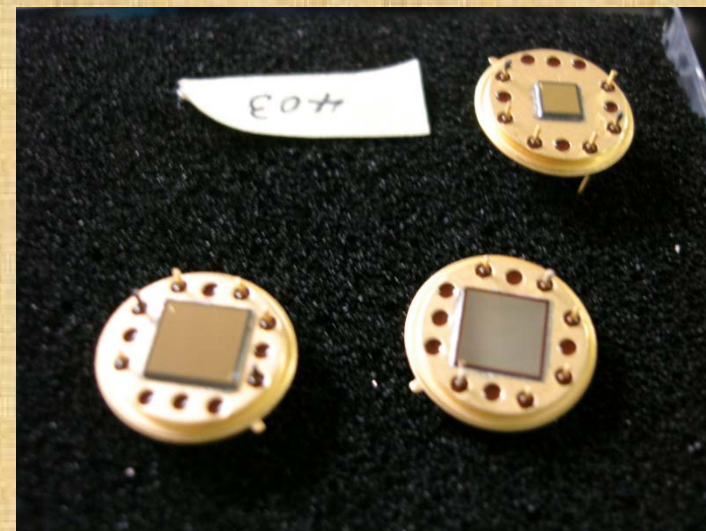




InP cell detector would observe scintillation light from LXe

Development of InP detector with thin thickness electrode



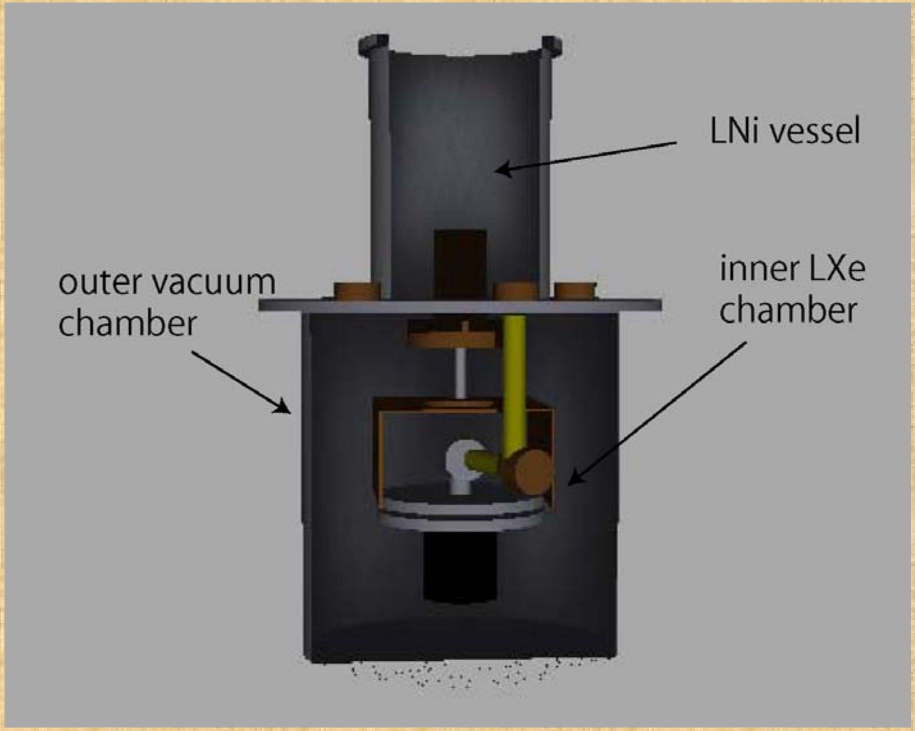


- Avoid attenuation of scintillation light in electrode
- Developed thin thickness of Au/Cr electrode (100 angstrom [10nm]) of InP cell detector
- Hard to observe CsI scintillation light

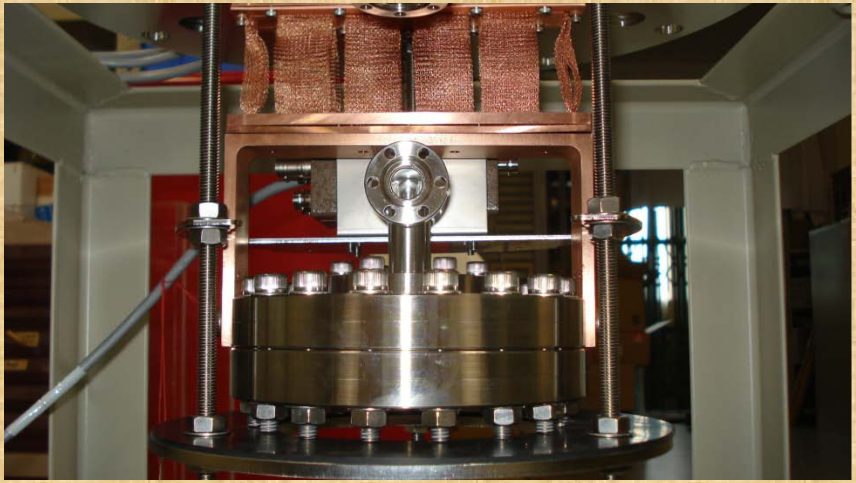
  need more thin electrode (50 angstrom ready!)

Development of LXe chamber for IPNOS phase-I

- 24cc Liquid Xenon (Lxe) in inner chamber
- 4 cell InP detector mounted inside of LXe
- PMT read out for the coincidence



Cooling test of Liquid Xenon chamber



For $0\nu\beta\beta$ experiment

$\beta\beta$ emitters with $Q_{\beta\beta}$ >2 Mev

Transition	$Q_{\beta\beta}$ (keV)	Abundance (%) ($^{232}Th = 100$)
$^{110}Pd \rightarrow ^{110}Cd$	2013	12
$^{76}Ge \rightarrow ^{76}Se$	2040	8
$^{124}Sn \rightarrow ^{124}Te$	2288	6
$^{136}Xe \rightarrow ^{136}Ba$	2479	9
$^{130}Te \rightarrow ^{130}Xe$	2533	34
$^{116}Cd \rightarrow ^{116}Sn$	2802	7
$^{82}Se \rightarrow ^{82}Kr$	2995	9
$^{100}Mo \rightarrow ^{100}Ru$	3034	10
$^{96}Zr \rightarrow ^{96}Mo$	3350	3
$^{150}Nd \rightarrow ^{150}Sm$	3667	6
$^{48}Ca \rightarrow ^{48}Ti$	4271	0.2

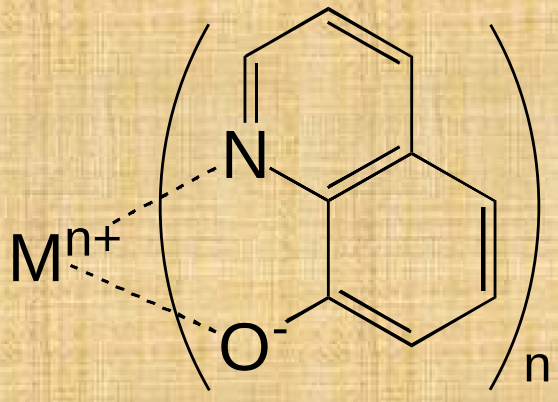
- Large Q value : above ^{208}Tl γ line (2.614MeV)
- metal complex solved in organic solvent

⇒ Zirconium (Zr) has 4 valence ion

Metal complex for liquid scintillator

- metal complex

  8-quinolinolate metal complex (MQ_n)



M = In, n = 3; M = Zr, n = 4

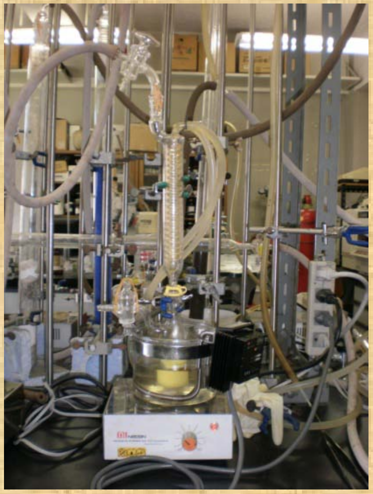
- ➢ AlQ_3 has been established as organic Electro Luminescence material (@530nm)
- ➢ InQ_3 and ZrQ_4 should also have same property of luminescence with almost same wavelength

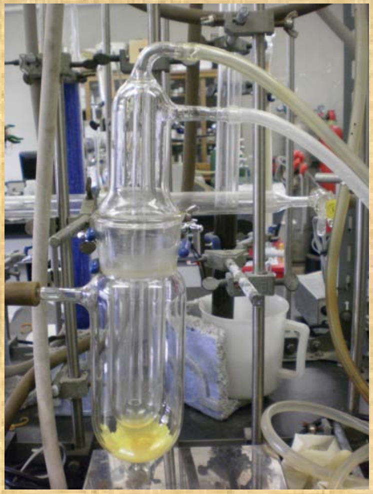
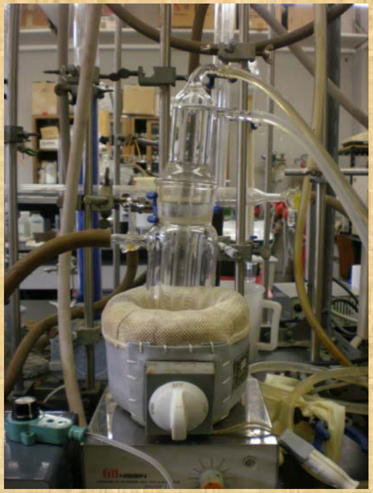
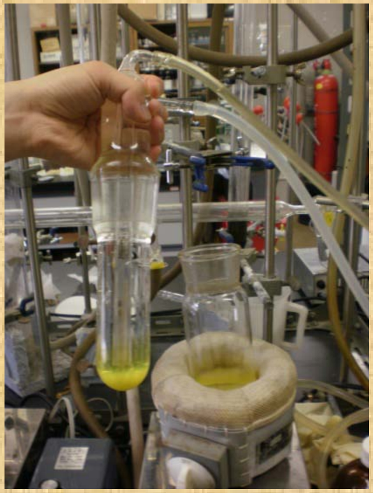
Goal

Light yield : 60% of BC505

Energy resolution : 4%@3MeV

Synthesis of ZrQ_4 and sublimation



InQ_3

- primary yield 100%
- sublimation 77%

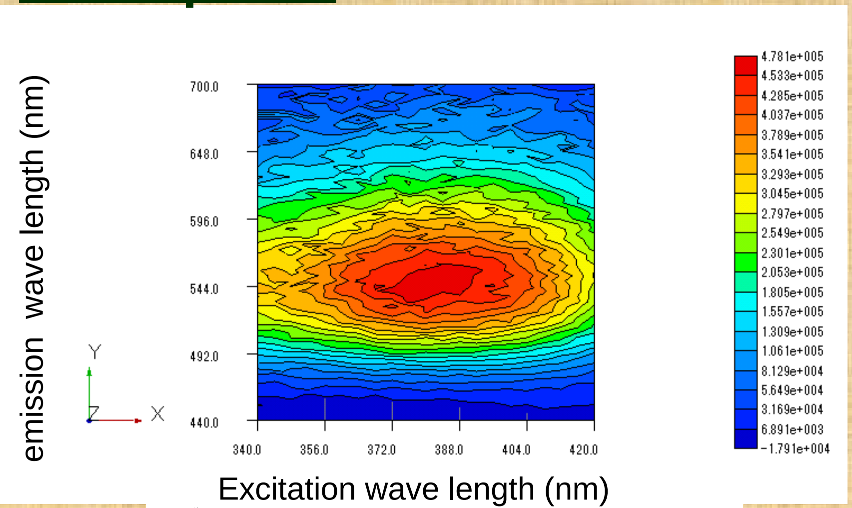
ZrQ_4

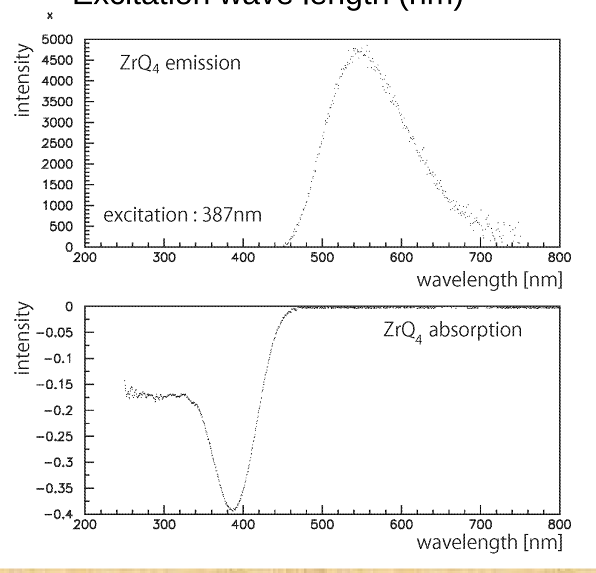
- primary yield 96%
- sublimation 70%

Solution InQ_3 and ZrQ_4 in organic solvent

- InQ_3 and ZrQ_4 dissolved in Benzonitrile (PhCN) with ~2%
  - Benzonitrile (PhCN: C_6H_5CN)
    density : 1.0g/mL
    flash point : 75°C
    photon emission : 291nm@maximum
    attenuation length : 66cm (@0.5wt%)
  - Liquid scintillator cocktail
    PhCN+PPO(100mg)+POPOP(10mg)
    PhCN+PPO(100mg)+bis-MSB(10mg)

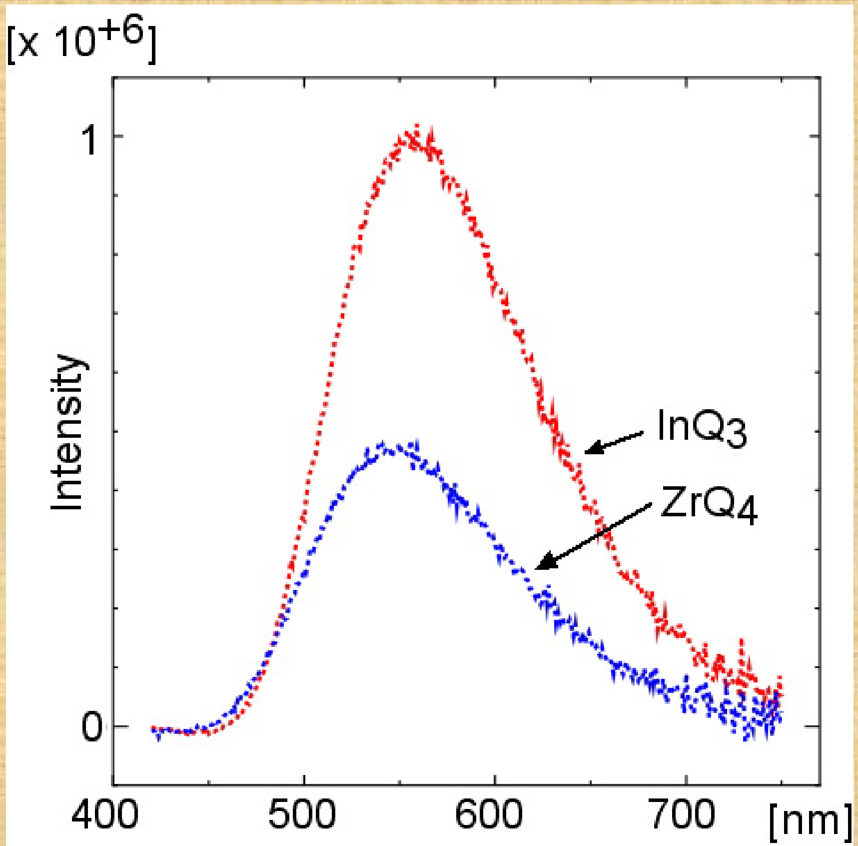
Photo Luminescence and absorption of ZrQ_4 complex





- Photo luminescence
  - Fluorescence device: HORIBA FluoroMax-4
  - Absorbance devie : HITACHI U-3000
  - Solvent : Benzonitrile (PhCN)
  - Concentration : 3.0×10^{-5} mol/L
  - Molecular mass : 667.84
  - Max. emission wavelength : 548.0nm
  - Max. absorption wavelength : 383.3nm

Quantum yield of InQ_3 and ZrQ_4 for photo luminescence



- Quantum yield
  - Fluorescence intensity (area of wavenumber spectra) of Quinine as standard (Ir)
  - Same intensity using corrected spectrum for InQ_3/ZrQ_4 was calculated (Is)
  - Absorbance of Quinine (Ar:0.34) and InQ_3/ZrQ_4 (As:0.19/0.39)
  - Quantum Yield is defined by

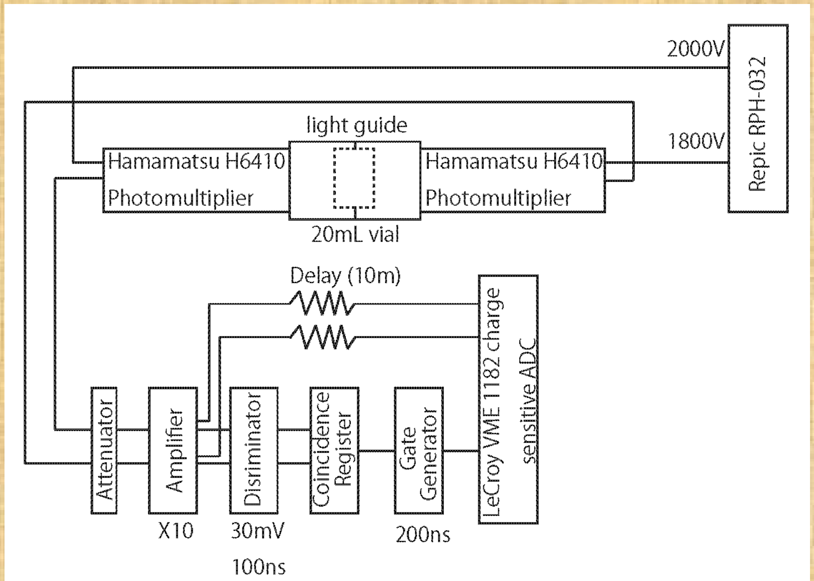
$$\boxed{\Phi s = \Phi r(Is/Ir)(Ar/As)}$$

$\Phi s(InQ_3) = 0.050$ [Is/Ir = 0.051]

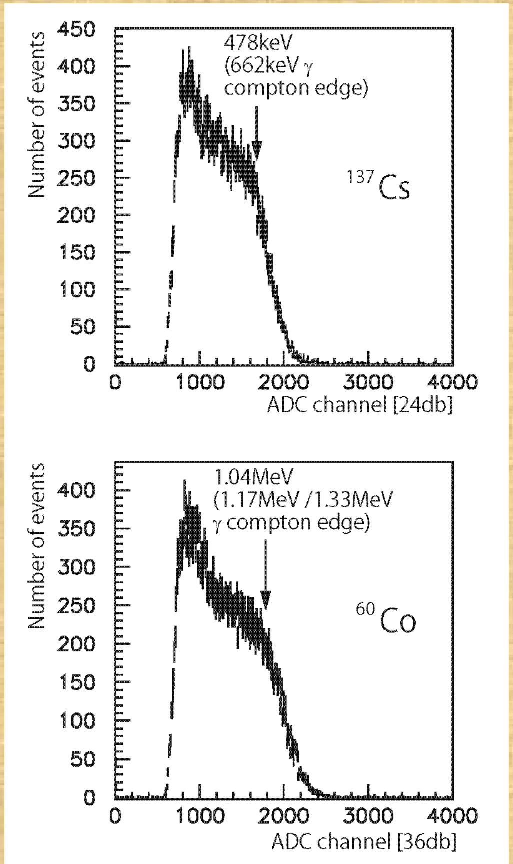
$\Phi s(ZrQ_4) = 0.011$ [Is/Ir = 0.023]

cf. $\Phi s(AlQ_3)=0.17$

DAQ setup



BC505 (standard scinti.)



1040keV :
1630ch@30db

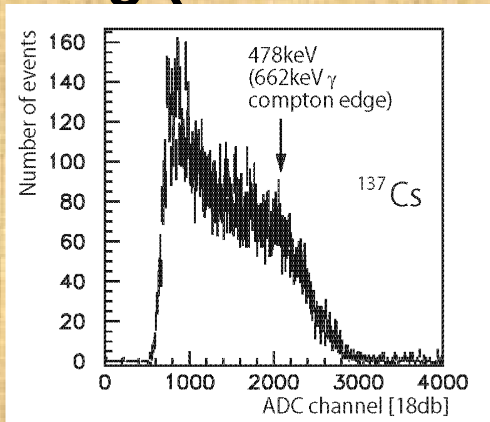
52160ch@0db
(QE : 0.25)

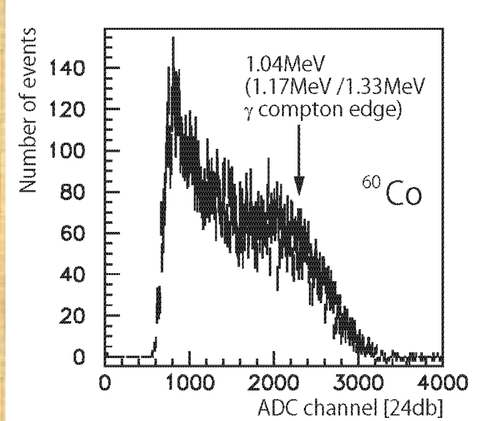
208640ch@0db

478keV:
1575ch@24db
expected :
1498ch

Comparison of light yield of PhCN based scintillator

PhCN/PPO100mg/POPOP 10mg (PhCN-POPOP)





1040keV :
2075ch@24db

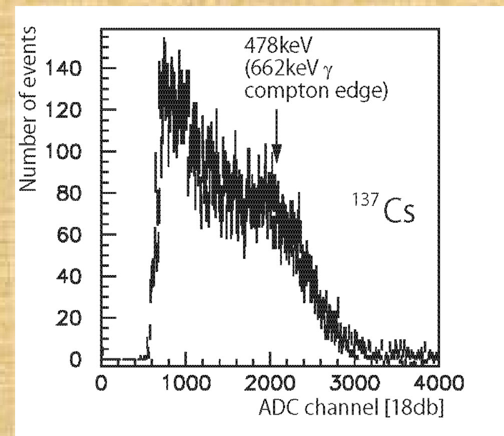
33200ch@0db
(QE : 0.25)

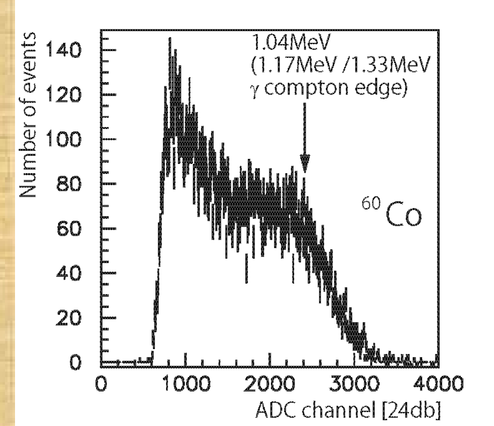
132800ch@0db

Light Yield
toBC505: 63%

478keV:
1875ch@18db
expected :
1907ch

PhCN/PPO100mg/bis-MSB 10mg (PhCN-bisMSB)





1040keV :
2255ch@24db

36080ch@0db
(QE : 0.25)

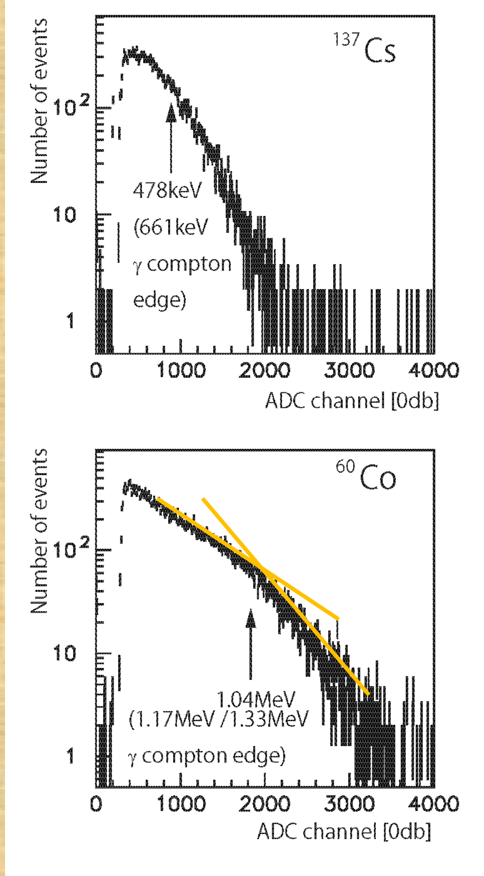
144320ch@0db

Light Yield
toBC505: 69%

478keV:
2025ch@18db
expected :
2072ch

Response for γ–ray from radioactive source : Light yield and quantum yield

InQ_3 50mg in PhCN-POPOP



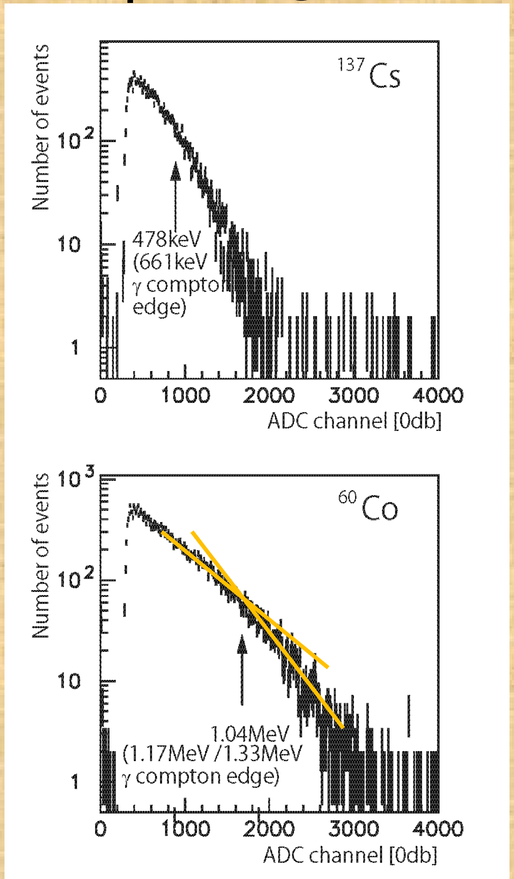
1040keV :
1925ch@0db
(QE : 0.093)

20699ch@0db

Quantum Yield :
20699/132800
=15.6%(5.0%)

Light Yield to
BC505:
20699/208640
=9.9%

ZrQ_4 50mg in PhCN-POPOP



1040keV :
1525ch@0db
(QE : 0.10)

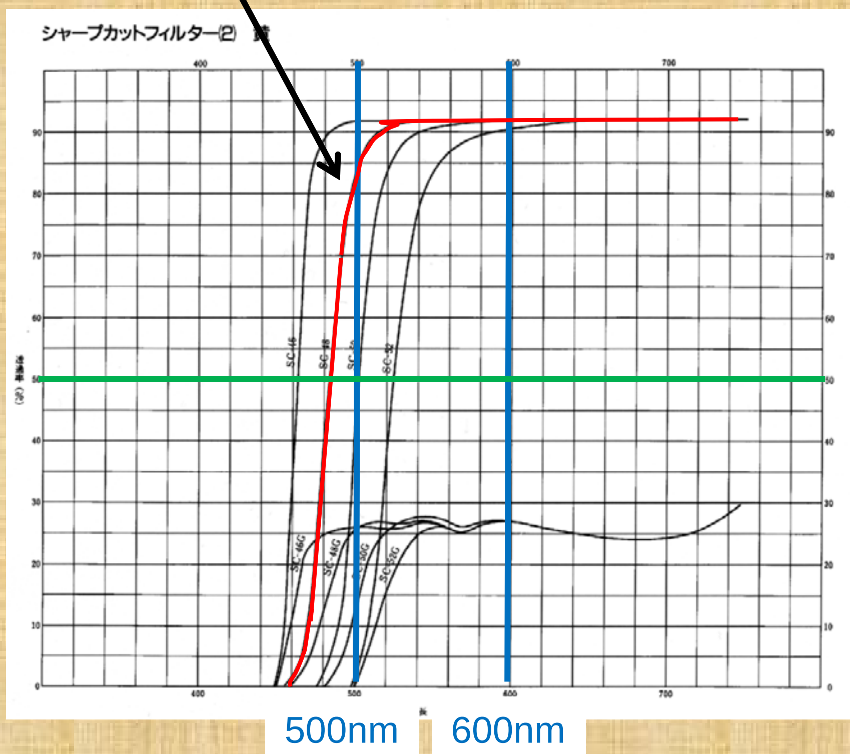
15250ch@0db

Quantum Yield :
15250/132800
=11.5%(1.1%)

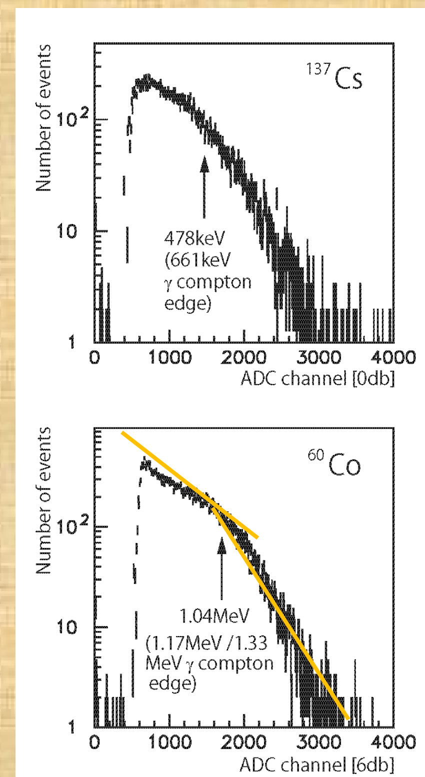
Light Yield to
BC505:
15250/208640
=7.3%

Response for γ–ray from radioactive source : PhCN scintillation light for λ > 530nm

FujiFilm SC-48 (λ > 530nm transparency : 92%)



PhCN-POPOP via SC-48



1040keV :
1525ch@6db

3050ch@0db
(QE : 0.10)

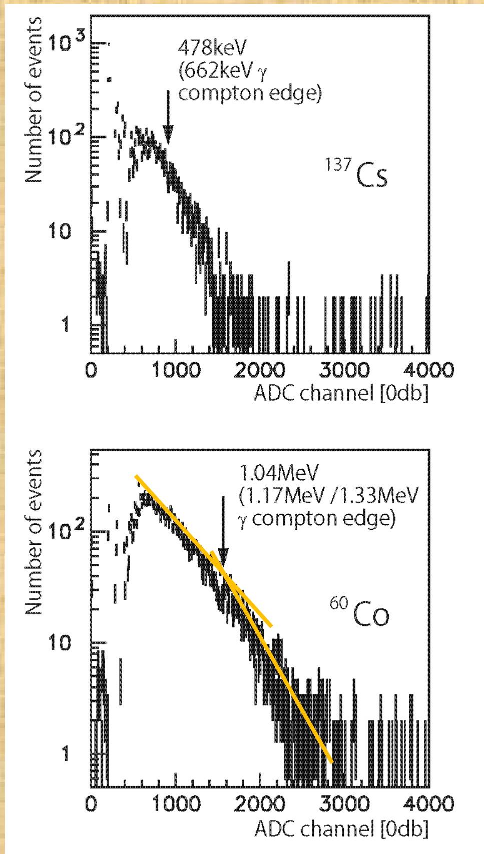
30500ch@0db

Light yield :
30500/132800
=23.0% remains

77% of light was λ < 530nm

Response for γ–ray from radioactive source : residual light in luminescence

InQ_3 50mg in PhCN-POPOP via SC-48



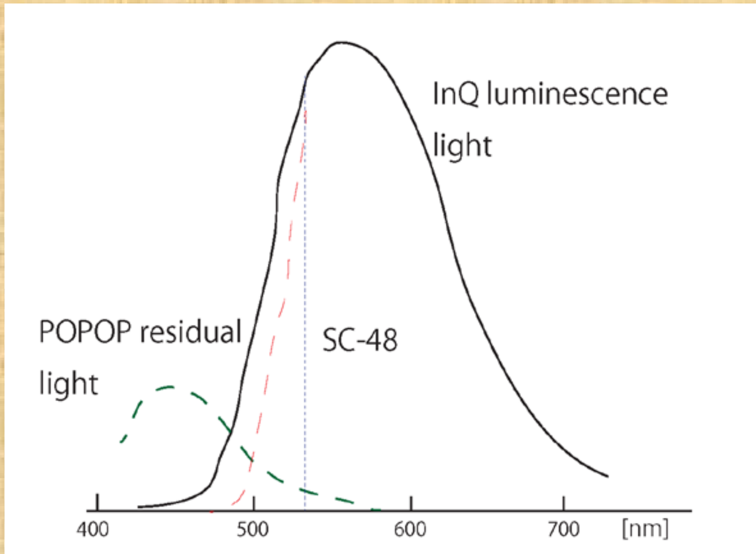
1040keV :
1280ch@0db
(QE : 0.093)

13763ch@0db

Light yield :
13763/20699
=66.5%

∴33.5% loss

residual lights in InQ_3 luminescence



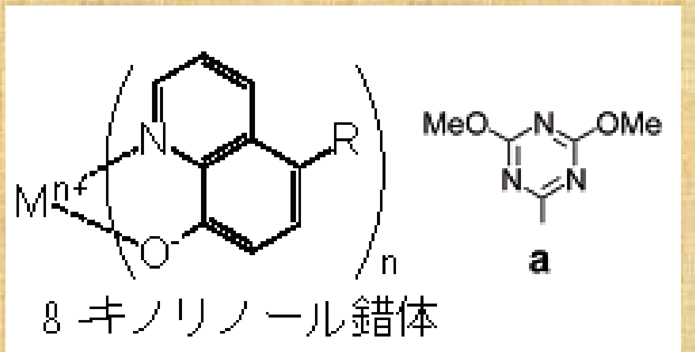
Most of the loss would be POPOP residual lights.

Most of light was caused by luminescence of complex

Conclusion

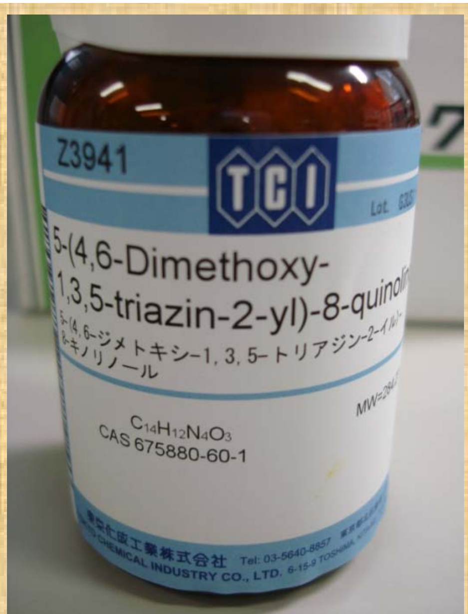
- InP detector for IPNOS needs more thin Au/Cr electrode (50 angstrom) to measure LXe scintillation.
- InQ_3 and ZrQ_4 loaded in PhCN scintillator have photo luminescence for γ irradiation.
- Transparency : ~66cm @ 558nm (0.5% dissolution)
- Light yield relative to BC505 : 9.9% and 7.3%
- Quantum yield : 15.6% / 11.5% (PL: 5.0% / 1.1%)
- Next step: modify 8-quinolinolate ligand to add substituent groups in order to both increase QY and shorten wavelength
- Possibility: (In) β-diketon complex solved 10wt.% in Anisole. Modify ligand to add same (e^- poor) substituent.

5-(4-6-dimethoxy-1,3,5-trianzin-2yl)-8-quinollinolate metal complex



complex	A_{max} (ϵ [$mol^{-1}\cdot cm^{-1}$])	λ_F [nm]	Φ_F[b]	τ_F [ns]	HOMO-LUMO gap [eV]
Alq_3	388 (7.0×10^3)	526	0.171	15.38	2.570
1a	390 (2.7×10^4)	490	0.533	29.50	3.255

(J.Org.Chem. 2004 69 1723-1725)



- Expected light yield
  - Quantum Yield:

    InQ_3 0.05 →0.15~0.4

    ZrQ_4 0.01→0.03~0.37
  - emission wavelength:

    ~530nm for InQ_3 QE 0.093→0.126

    ~524nm for ZrQ_4 QE 0.10→0.13

4~11 times larger light yield will realize