Development of Halide Scintillation Crystals for HHCal Concept

Guohao Ren, Dingzhong Shen

Shanghai Institute of Ceramics

20100509 IHEP,Beijing

Outline

1. Introduction
2. CsI(Tl) crystal
3. PbF2 Cherenkov radiation materials
4. PbClF scintillation performance
5. Conclusion

1. Introduction

- Scintillators
  - Inorganic
    - Single crystals
      - Halides，CsI(Tl)
      - Oxides，BGO
    - Ceramics
    - Glasses
  - Organic
    - Plastics
    - Liquid scintillator

1. Introduction

Halide scintillators

- **Alkali Halides** — **AX type (NaI, CsI)**
- **Alkali Earth Halides** — **AX2 type (BaF2, SrI2)**
- **Rare earth trihalides** — **LaX3 (CeF3, LaCl3)**

Activators: Tl^{+}, Ce^{3+}, Eu^{3+}

Main Properties of some halide crystals

Parameters	BGO	BSO	CsI(Tl)	PbF_2	PbClF
Crystal Structure	cubic	cubic	cubic	cubic	tetra
$\rho(g/cm^3)$	7.13	6.8	4.51	7.77	7.1
n @λmax (nm)	2.15	2.06	1.84	1.82	2.2
τ (ns)	300	100	1000	?	10-30
λmax (nm)	480	480	560	?	400-500
Cutoff (nm) Edge	300	295	340	250	~300
Relative L.Y.	100	20		?	17%
Melting Point (℃)	1050	1030	621	842	600

Growth Method of halide Crystals

1）Chockralski method

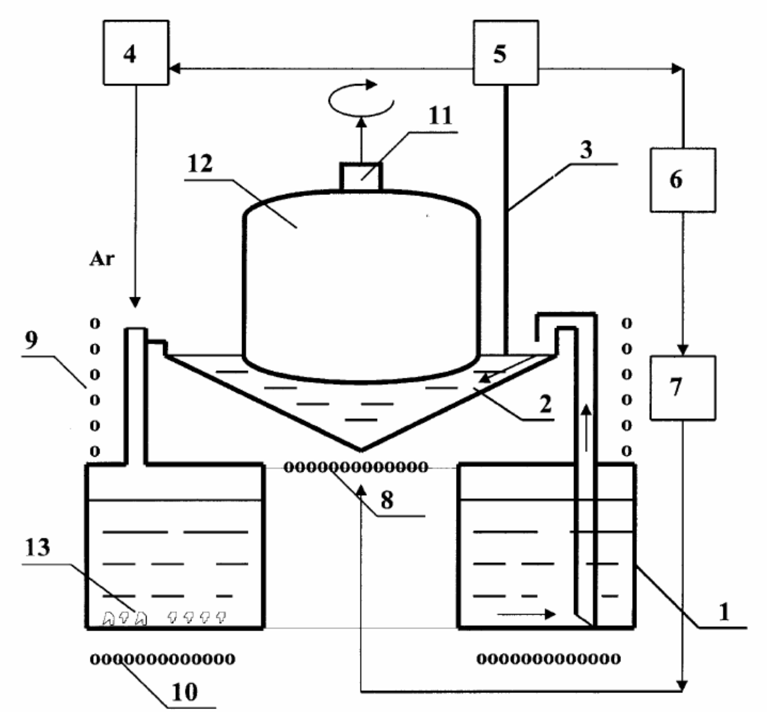
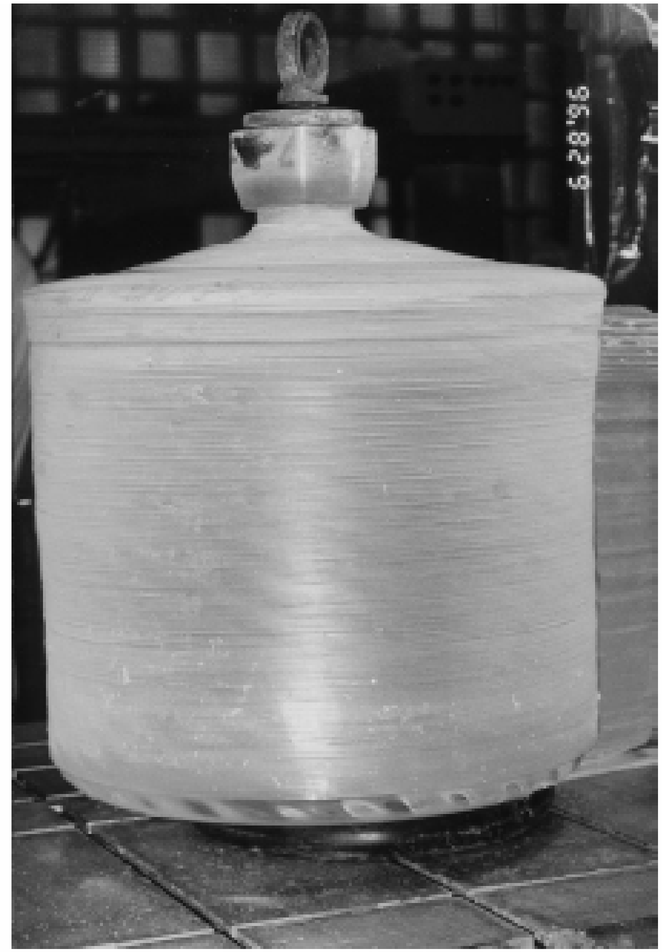


Fig. 1. Block – scheme of “KRISTALL” installation: (1) feeder, (2) crucible, (3) probe, (4) melt level regulator, (5) gas valve, (6) IBM PC, (7) temperature correction block, (8) bottom heater, (9) side heater, (10) heater of feeder, (11) seed, (12) crystal, (13) small piece of titanium.



B.G.Zaslavsky, et al., JCG,198/199,1999:856-859 CsI(Tl) ϕ430mm

Method 2: Modified Bridgman-stockbager

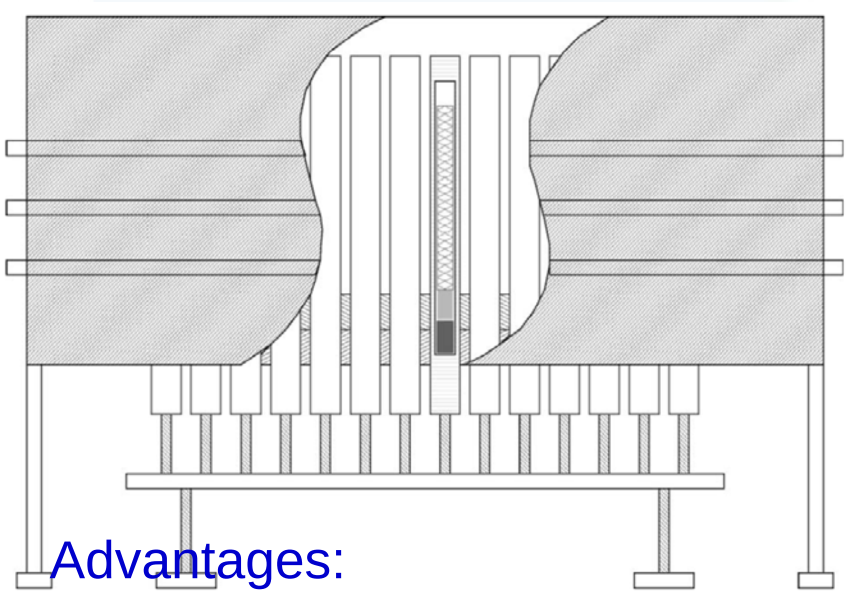
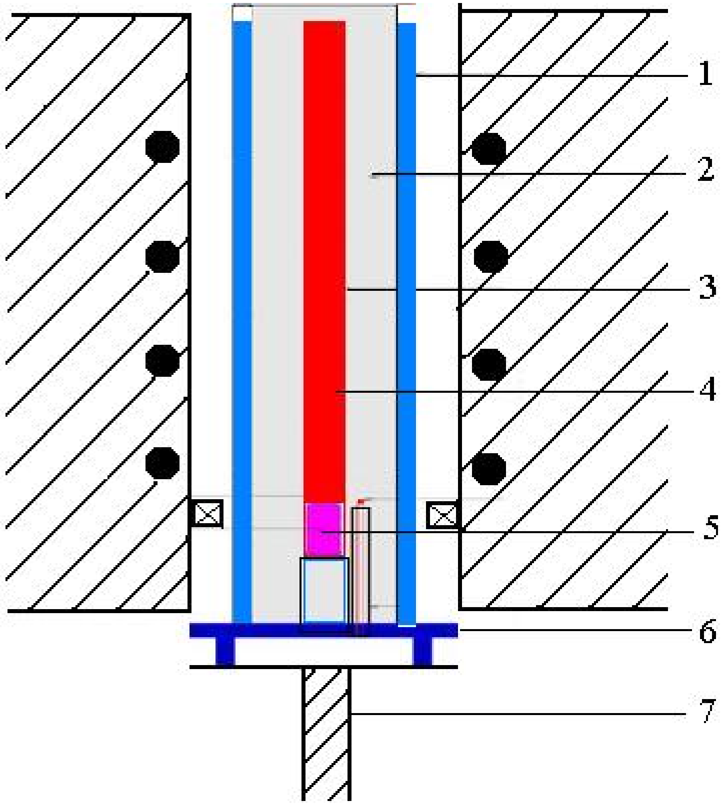


Fig. 2. A schematic of a typical Bridgman furnace with 28 crucibles.

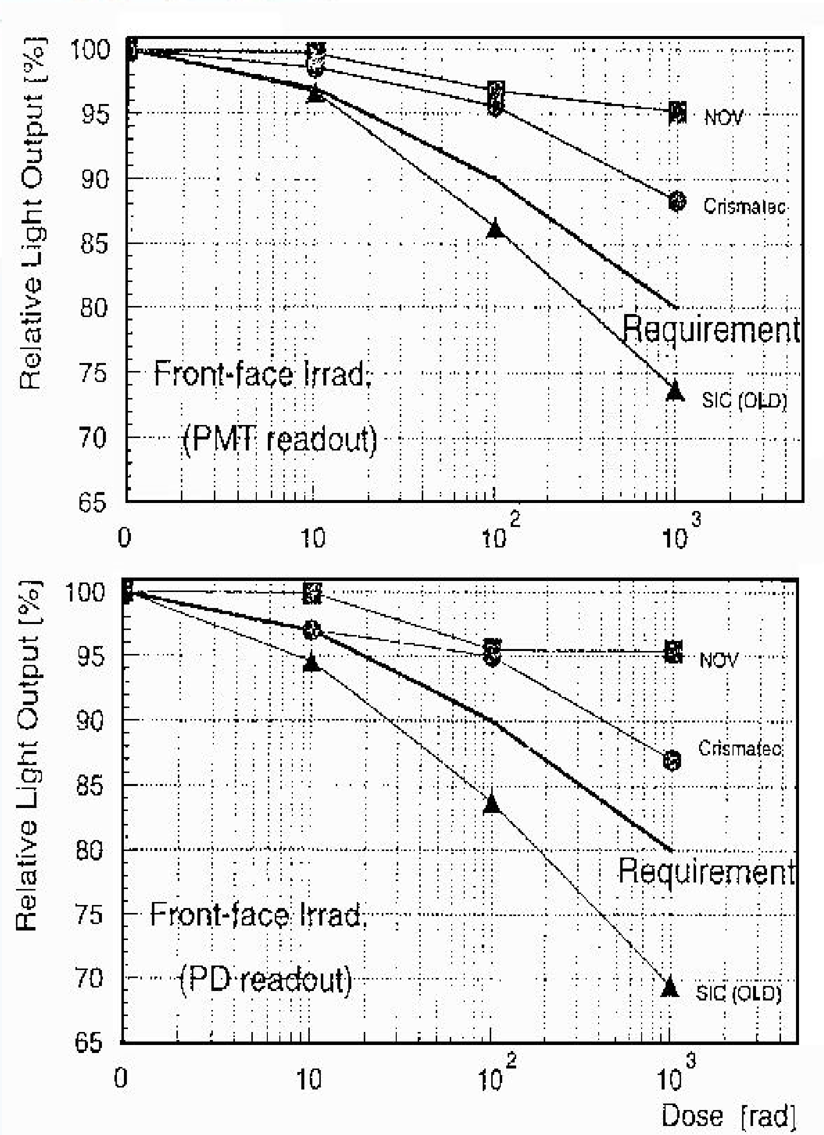
Advantages:

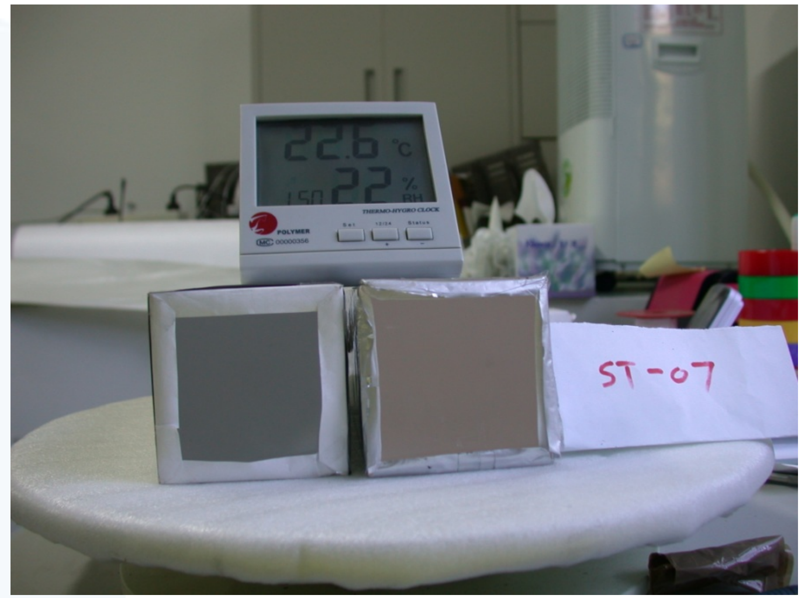
1) Low infrastructure investment
2) Simplified the techniquue
3) Suitable for mass production

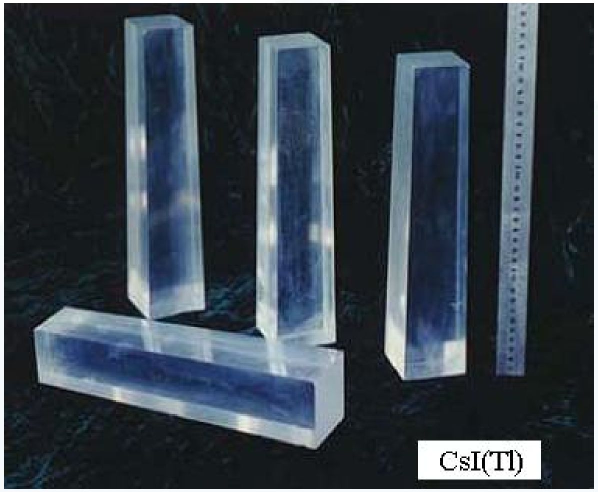


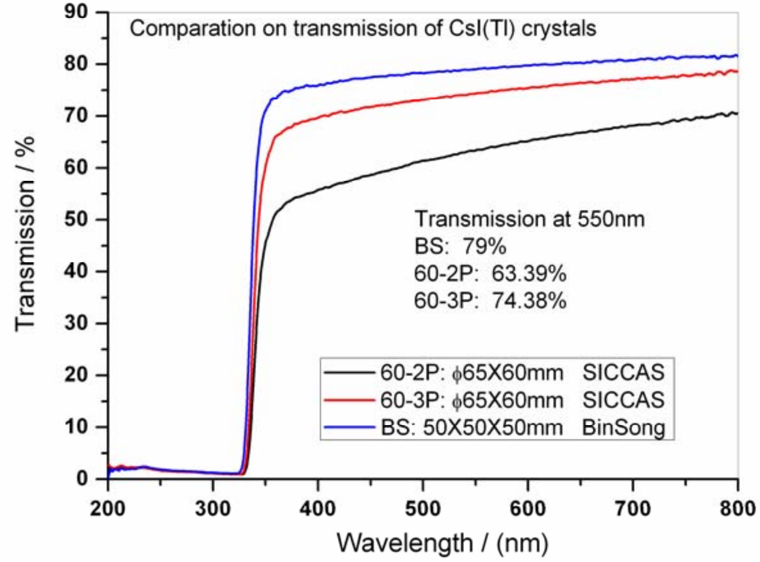
Growth Assembly of Bridgman Method

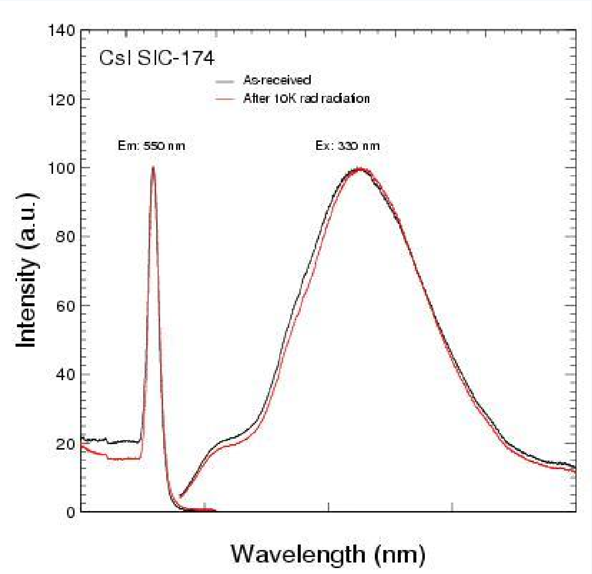
2.1 CsI(Tl) crystal

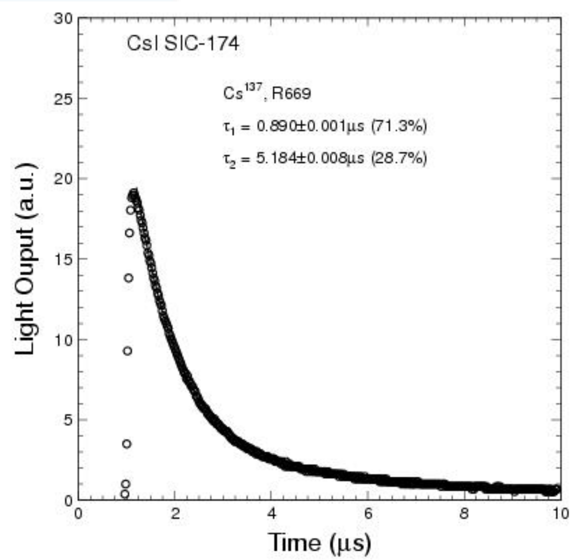





CsI(Tl)


Comparation on transmission of CsI(Tl) crystals
Transmission at 550nm
BS: 79%
60-2P: 63.39%
60-3P: 74.38%
60-2P: ϕ65X60mm SICCAS
60-3P: ϕ65X60mm SICCAS
BS: 50X50X50mm BinSong
Transmission / %
Wavelength / (nm)
0
10
20
30
40
50
60
70
80
90
200
300
400
500
600
700
800


CsI SIC-174
As-received
After 10K rad radiation
Em: 550 nm
Ex: 330 nm
Intensity (a.u.)
Wavelength (nm)
0
20
40
60
80
100
120
140


CsI SIC-174
Cs137, R669
τ1 = 0.890±0.001μs (71.3%)
τ2 = 5.184±0.008μs (28.7%)
Light Ouput (a.u.)
Time (μs)
0
5
10
15
20
25
30
0
2
4
6
8
10

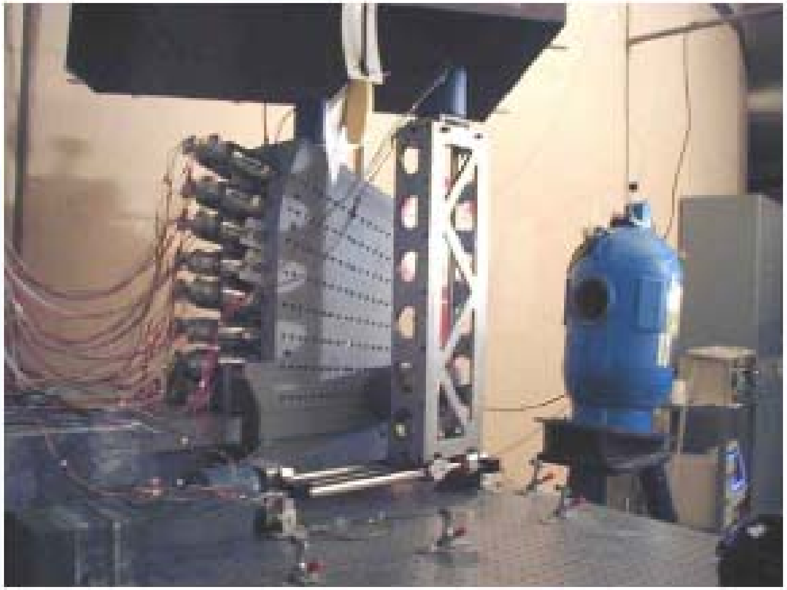


Fig. 1. Experimental setup: crystal array on the left, ^{60}Co source on the right.

BaBar

6240 pieces crystals (~26 tons)

Size:(47×47)×300×(60×60)mm

Energy range: ~1GeV

BESIII:

16 Types

Size: 66×63×280mm

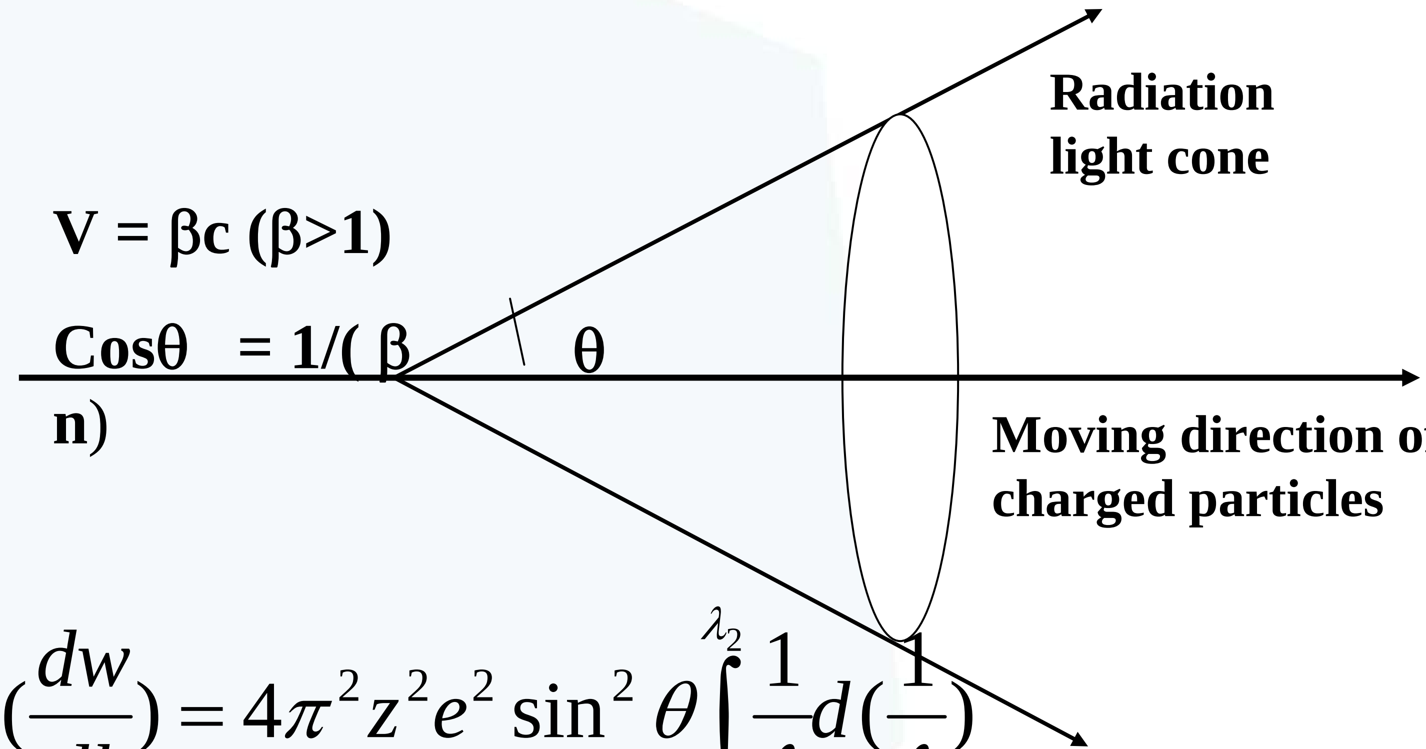
Nomber:1920pieces

Total volume:1740657.6cc

3. PbF2 and Its Cherenkov Effect

V = βc (β>1)

Cosθ = 1/(β n)



$$\left(\frac{dw}{dl}\right) = 4\pi^2 z^2 e^2 \sin^2\theta \int_{\lambda_1}^{\lambda_2} \frac{1}{\lambda} d\left(\frac{1}{\lambda}\right)$$

PbF_2-
An Excellent Cherenkov Radiation materials

Lead Glass	Rerective Index	Density (g/cm³)	RL (cm)	Crit. E (MeV)
F-2	1.62	3.61	3.22	17.3
SF-5	1.67	4.08	2.54	15.8
SF-6	1.81	5.20	1.69	12.6
PN-123	1.73	4.70	2.10	
F101	1.65	3.86	2.78	17.97
PbF_2	**1.82**	**7.77**	**0.93**	

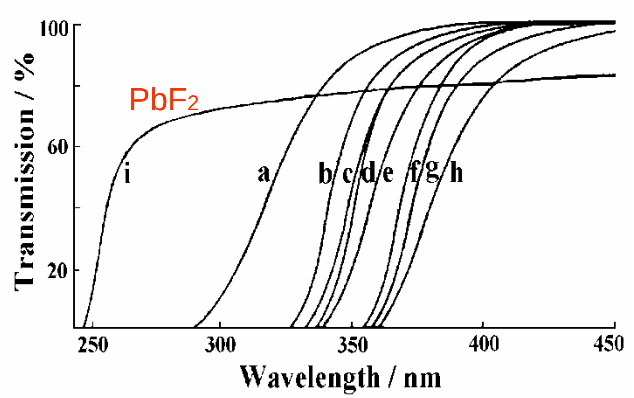
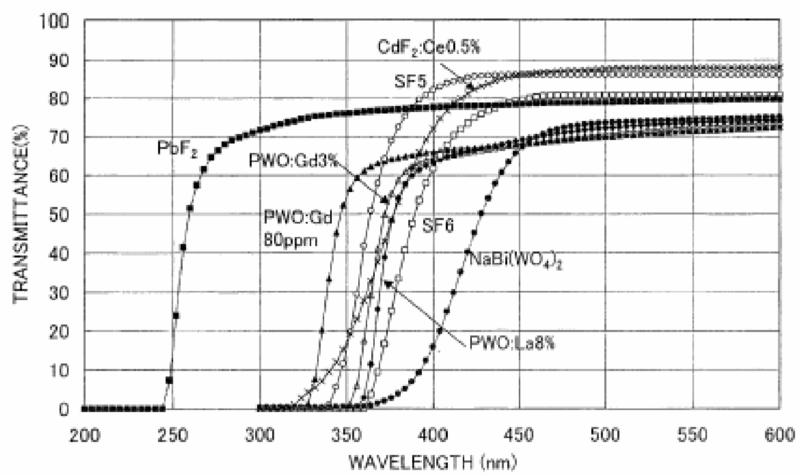
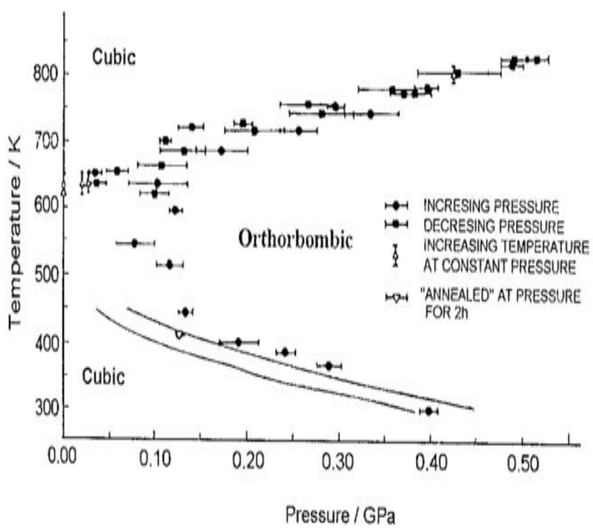


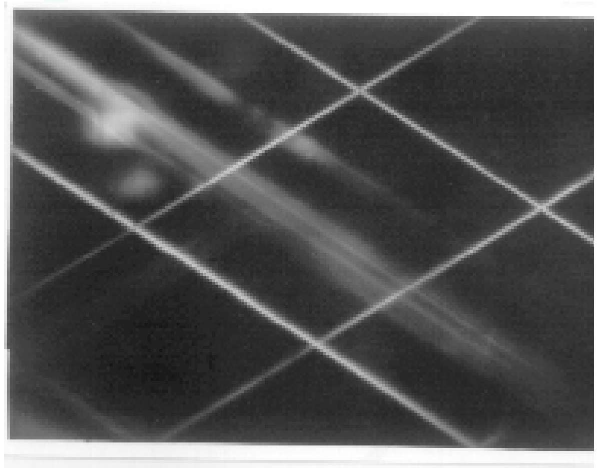
图3 氟化铅晶体与铅玻璃的透光率曲线 ($L=1X_0$)
Fig.3 Transmission curves of lead glass and a PbF_2 crystal per one radiation length (a-h: lead glass, a:PN-123, b:F-2, c:SF-2, e: SF-6, i: PbF_2 crysal)

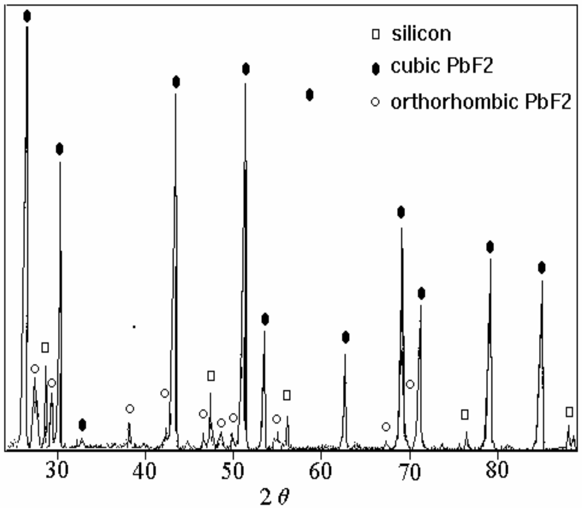
- PbF2 was Proposed as Cherenkov radiator by Williams in1957 and; Dalley in1968
- oxygen contamination
- Traditional growth method-vacuum
- New growth technique-non vacuum bridgman

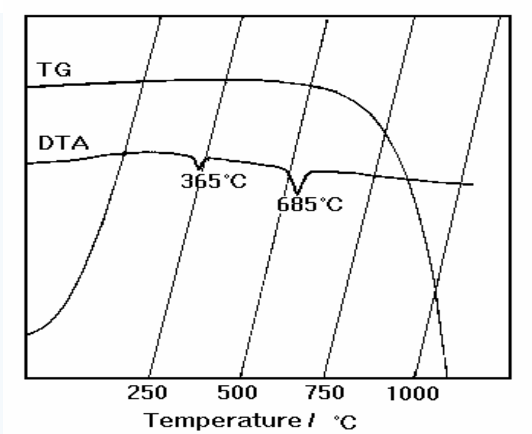


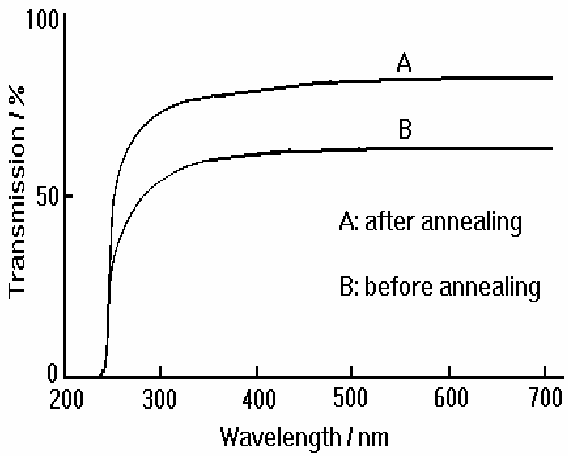
Crystal Growth and Crystal Defects









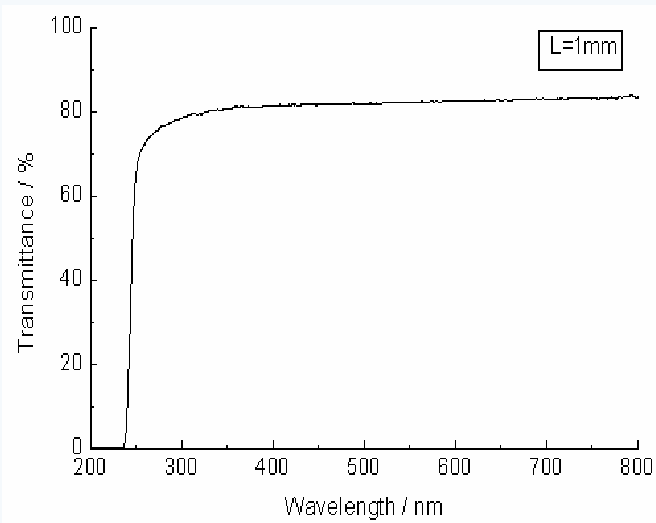


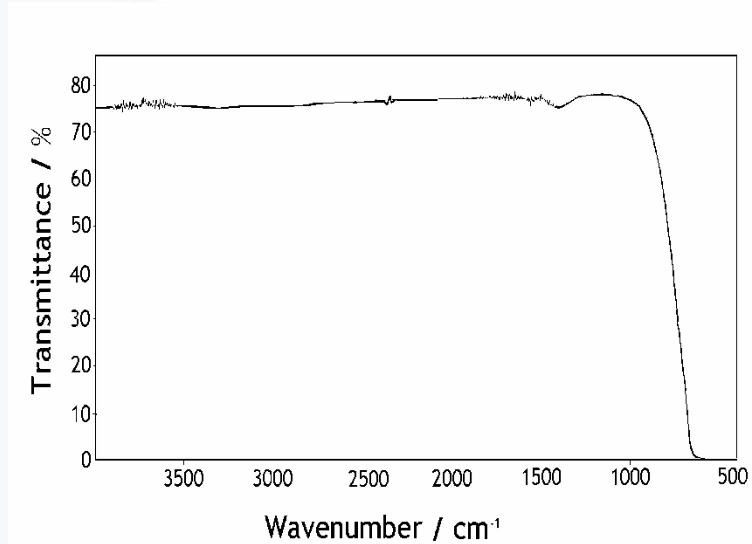
Heating: α-PbF2(orth.) $\rightarrow$ β-PbF2(cubic) $\rightarrow$ melt

Cooling: melt $\rightarrow$ β-PbF2(cubic)+ α-PbF2(orth.)

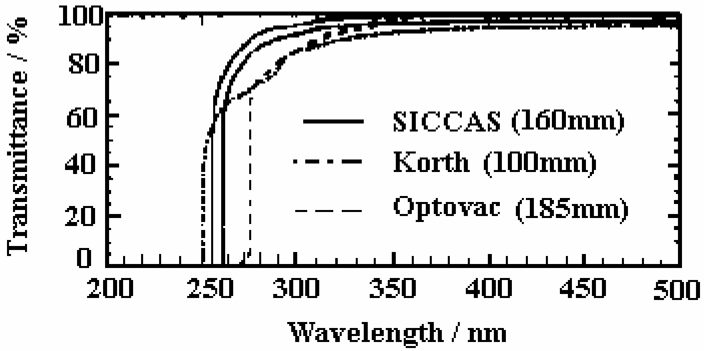
Annealing: α-PbF2(orth.) $\rightarrow$ β-PbF2(cubic)

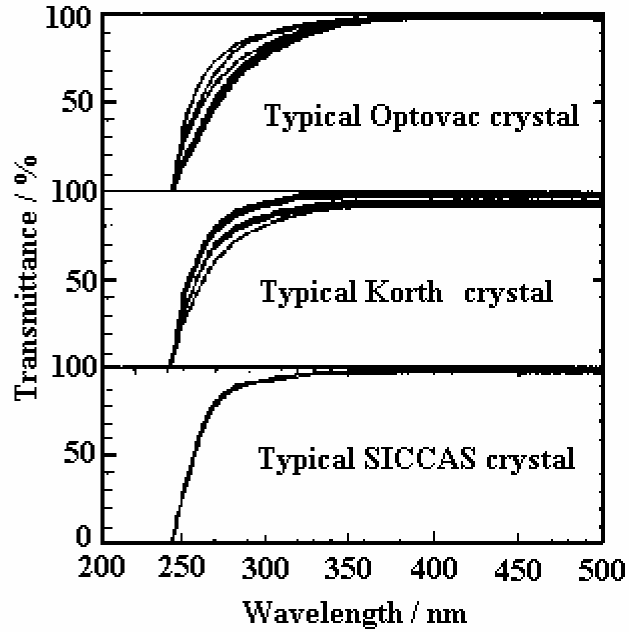
Boule size:
75×75×280 mm

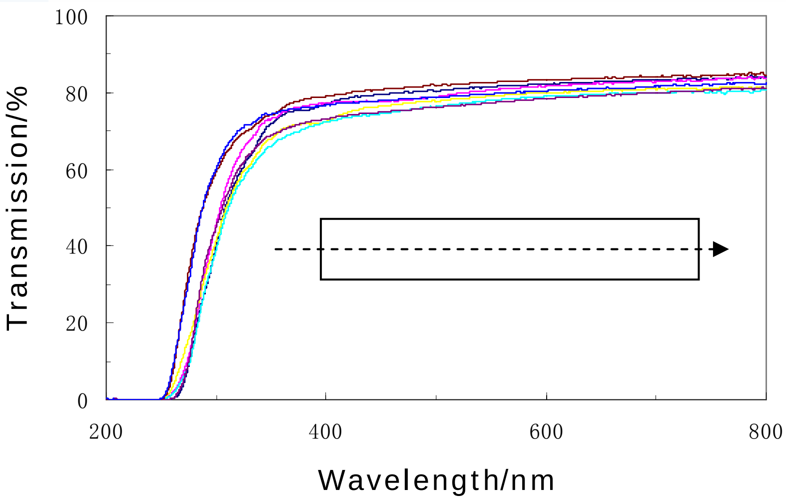


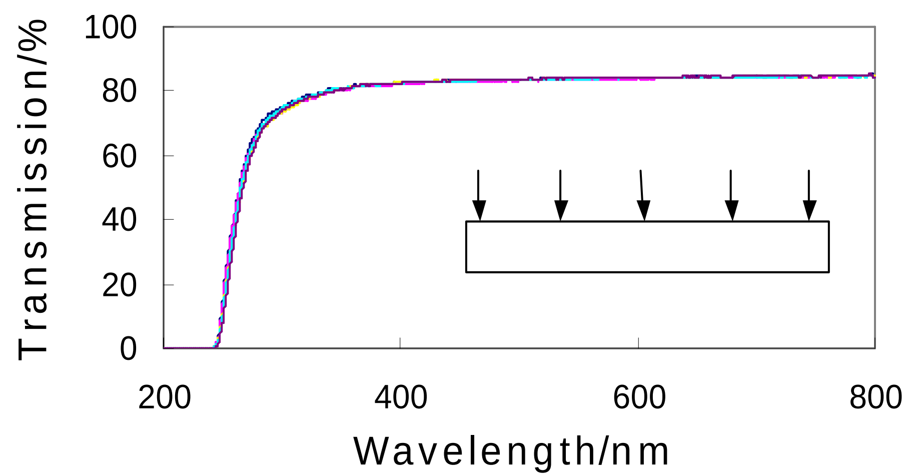


Transmission range: 245nm-14,000nm









Crystal Size: 30×30×186 mm

P. Achenbach et al., Nucl. Instr. And Meth., A416(1998)357-363

Light yield of Cherenkov radiation in PbF2

thods in Physics Research A 465 (2001) 318–328

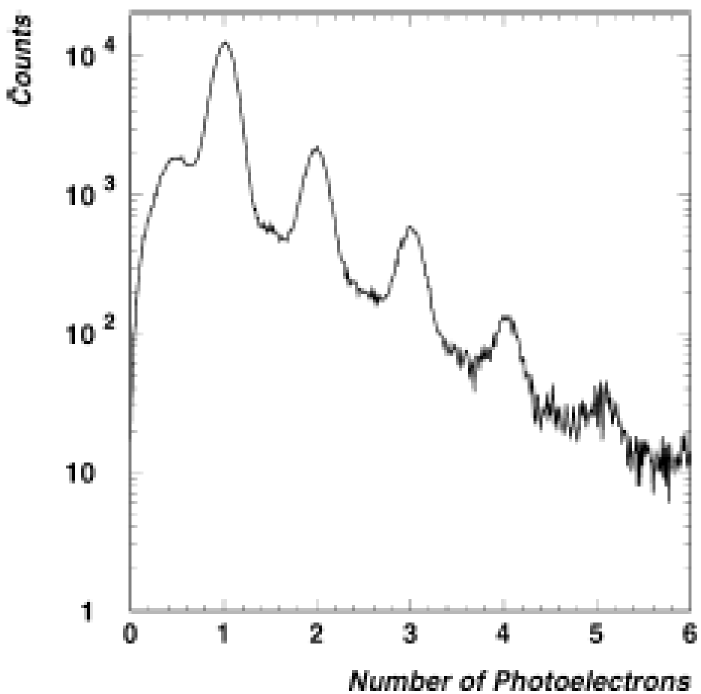
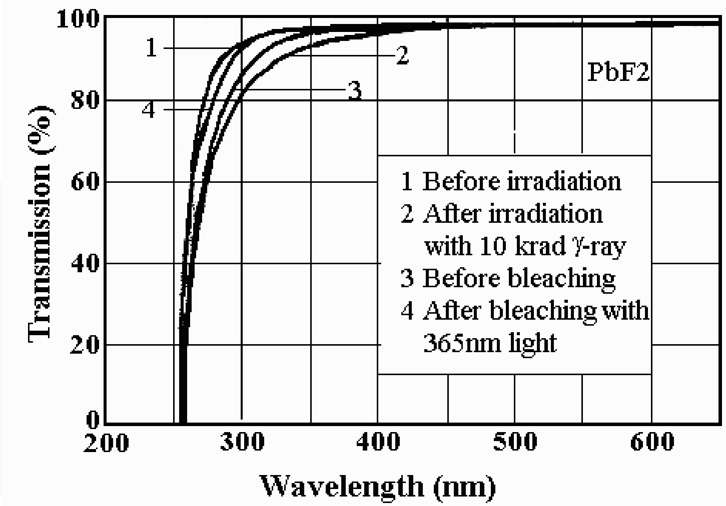


Fig. 4. A typical photoelectron distribution of a PbF_2 crystal from the series of measurements with the ^{60}Co γ-source. The distribution corresponds to the mean number of photoelectrons $\langle n \rangle_{mean} = (1.38 \pm 0.05)$ p.e. from which a LY of 1.7 p.e./MeV was derived.

Crystal size:
5×25×25mm
Light yield:
1.9p.e./MeV

Crystal size:
(30×30)×150×(30×30)
Light yield:
1.7p.e./MeV

P. Achenbach et al., Nucl. Instr. And Meth., A465(2001)318-328



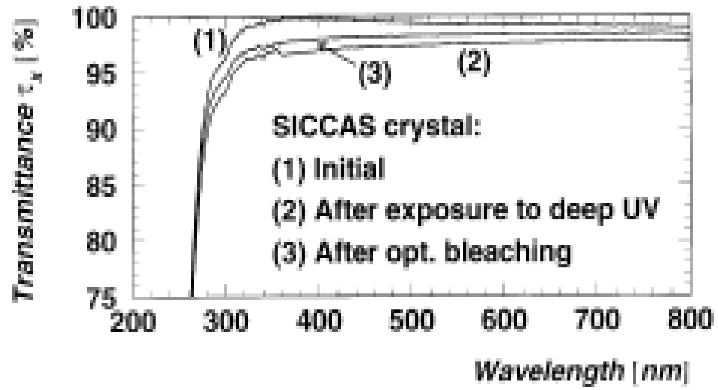


Fig. 9. Decrease of the apparent internal transmittance τ_x^i in PbF_2 caused by 40 min of illumination with deep ultraviolet light. Curve (3) shows the effect of 20 h of optical bleaching with blue light.

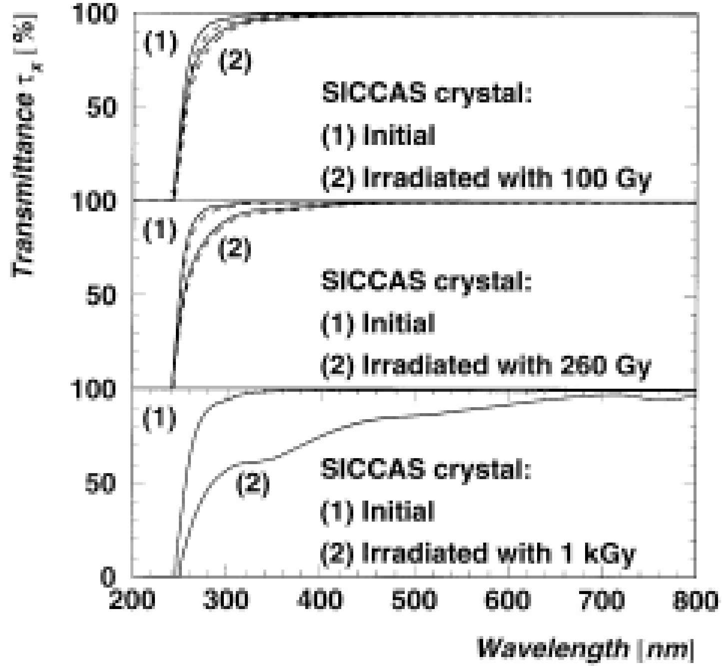


Fig. 5. Spatial dependence of the radiation damage in different PbF_2 crystals from SICCAS. The internal transmittance τ_x^i perpendicular to the longitudinal axis before and after γ-irradiation with different doses is shown. Top: 1 kGy. Bottom: 7 kGy. The longitudinal positions are encoded as follows: solid = 1 cm; dashed = 5 cm.

P. Achenbach et al., Nucl. Instr. And Meth. in Phys.Res., A416, 357

Dependence of resolution on energy

表 2 氟化铅晶体的能量分辨率

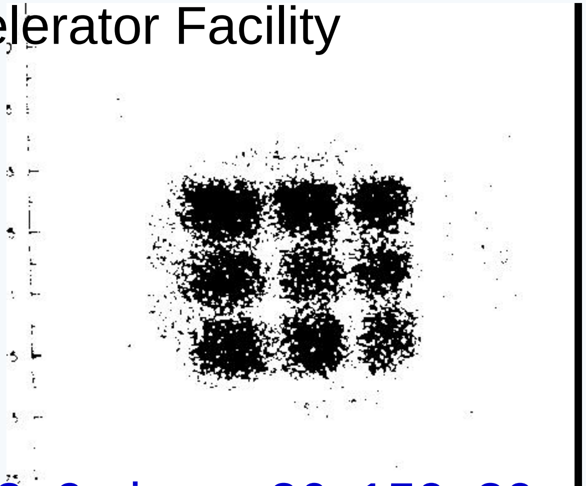
Table 2 Energy resolution of lead fluoride crystals

Supplier	Crystal size/mm	Energy/MeV	Resolution/%
OPTOVAC[7]	21×21×186	1000	5.9
		2000	4.1
		3000	3.4
		4000	3.4
SiC*	30×30×185.4	855	3.5
		734	3.7
		450~705	$3.2/\sqrt{E}$

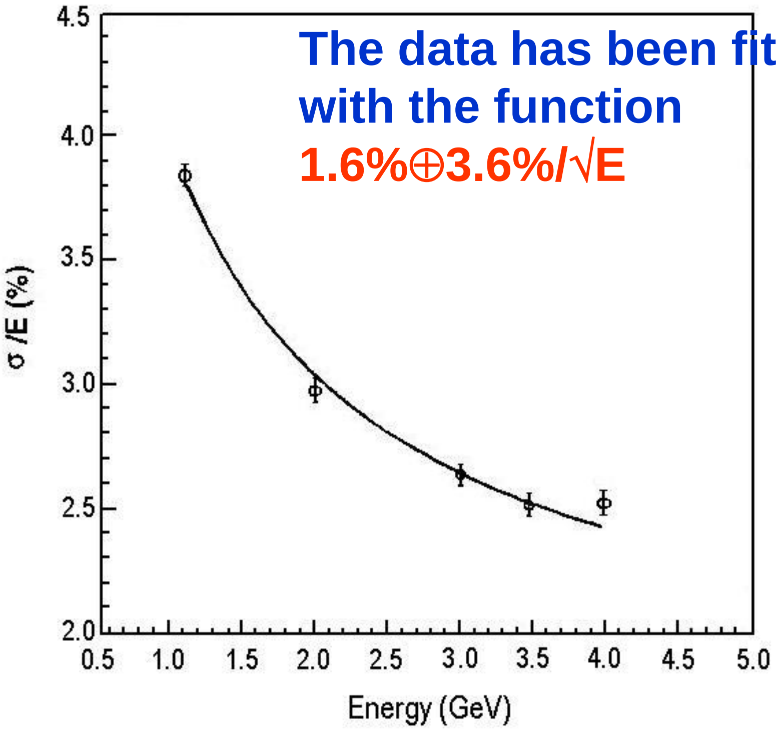
Energy resolution of PnF2

The State University of New Jersey

Thomas Jefferson national Accelerator Facility



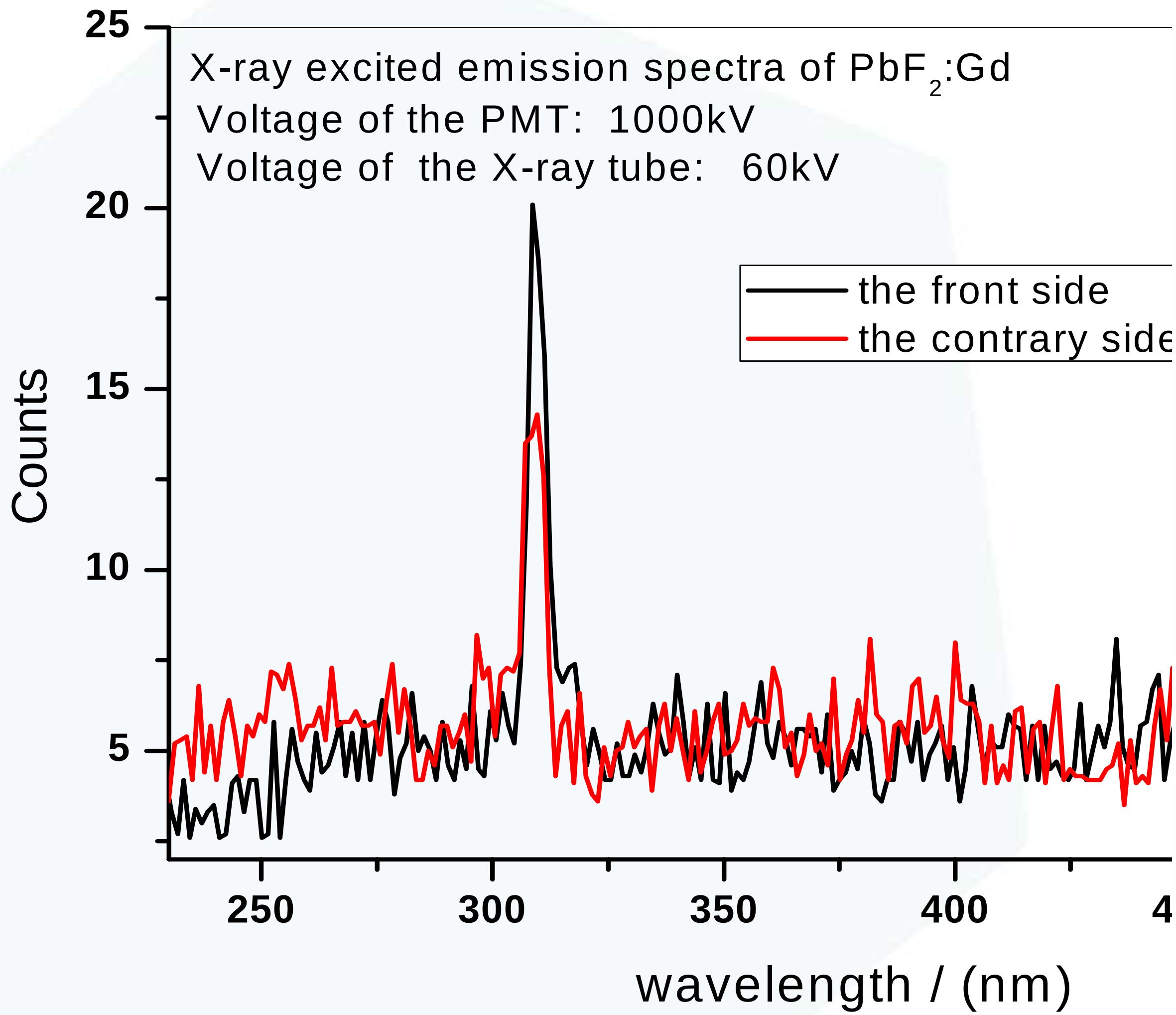
3×3=9 pieces;26×150×30mm

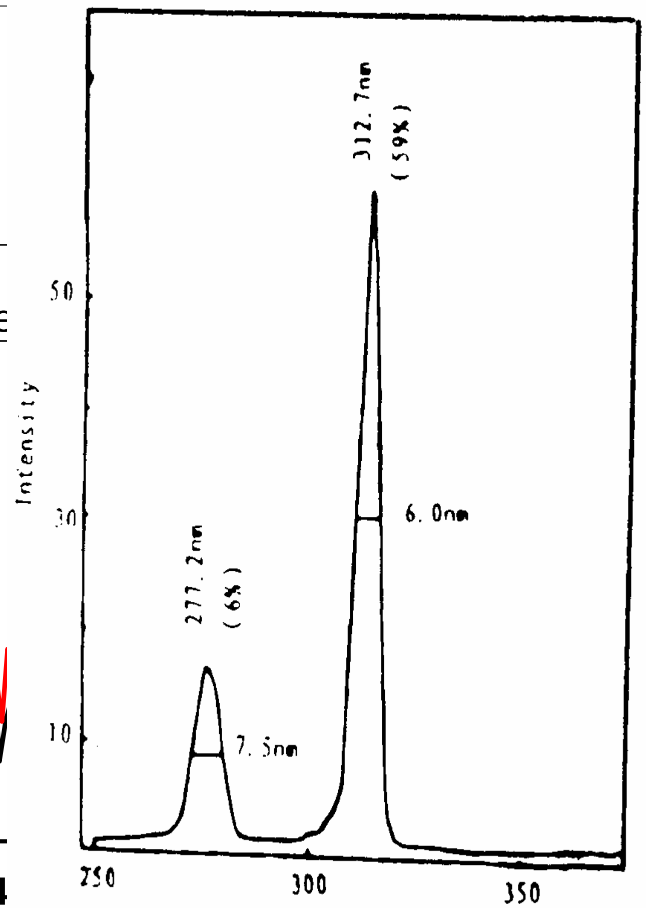


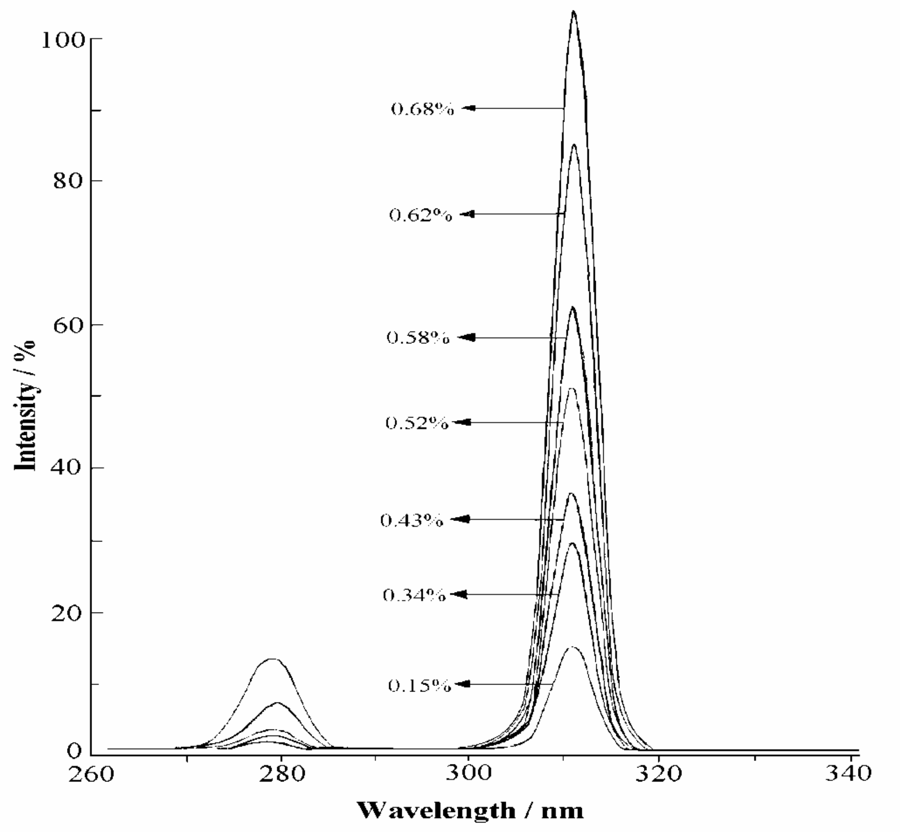
The data has been fit with the function $1.6\% \oplus 3.6\%/\sqrt{E}$

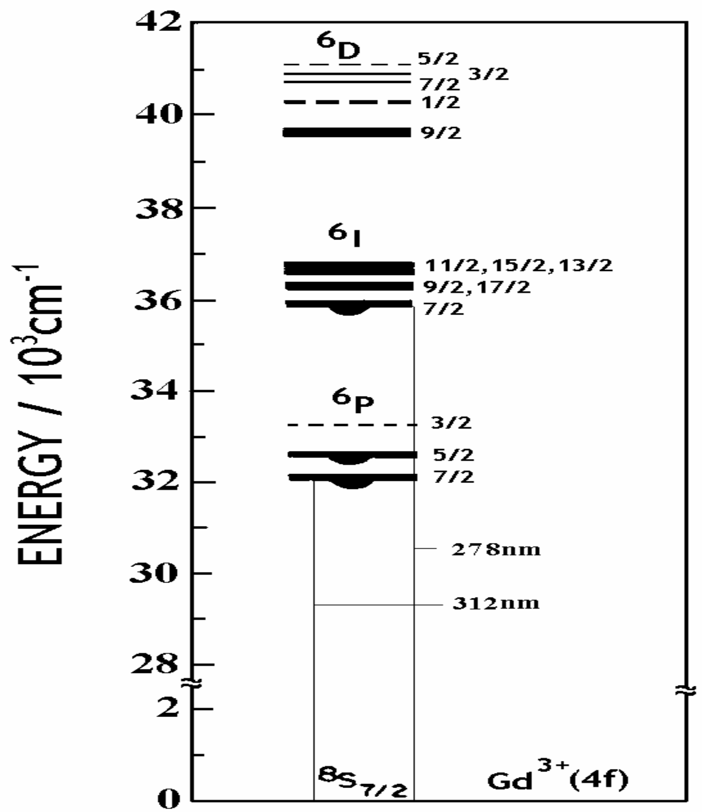
The resolution of the nine-cell PbF2 crystal test calorimeter as a function of energy (From Kathy McCormick and Sirish Nanda)

Doping effect of PbF2 by Gd

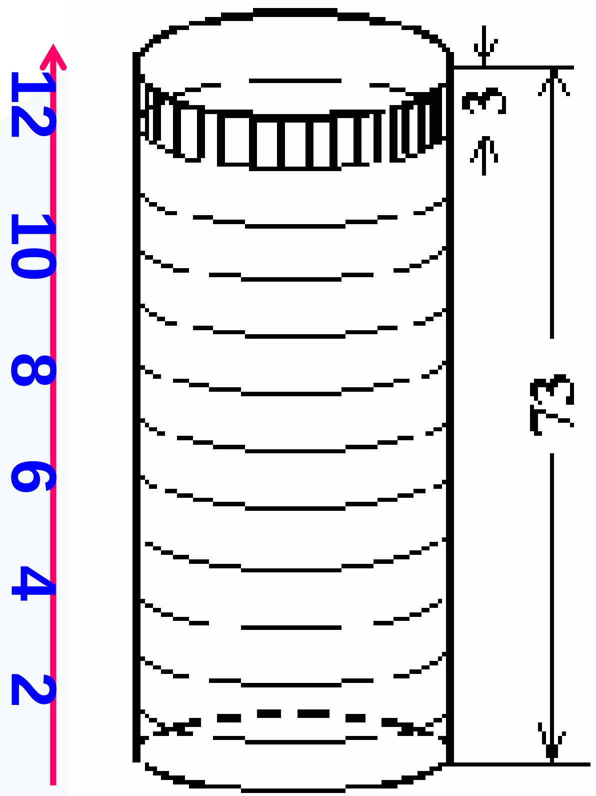


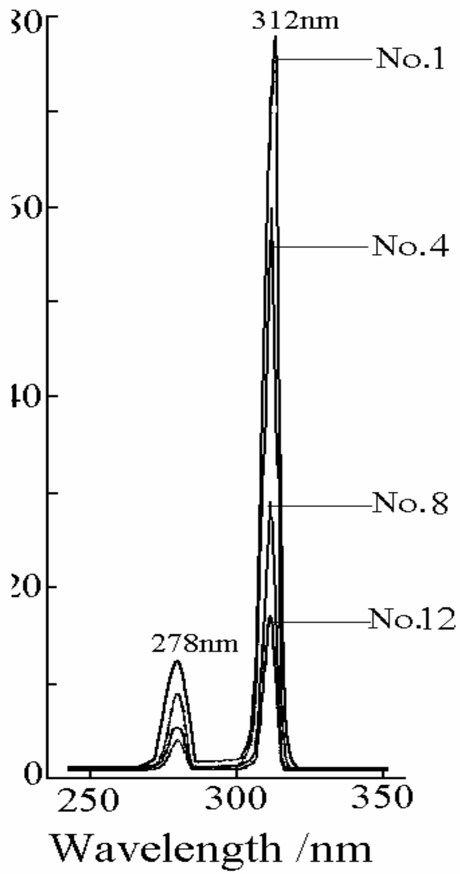


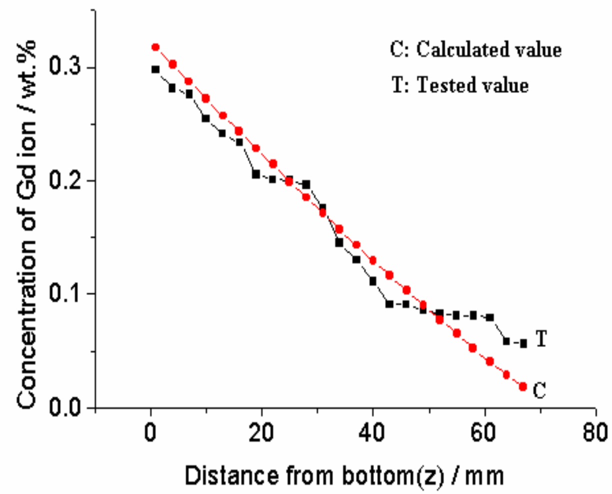

Intensity / %
Wavelength / nm
0.68%
0.62%
0.58%
0.52%
0.43%
0.34%
0.15%
100
80
60
40
20
0
260
280
300
320
340


ENERGY / 10^3cm^{-1}
^{6}D
5/2
3/2
7/2
1/2
9/2
^{6}I
11/2,15/2,13/2
9/2,17/2
7/2
^{6}P
3/2
5/2
7/2
278nm
312nm
$^8S_{7/2}$
Gd^{3+}(4f)
42
40
38
36
34
32
30
28
2
0

Dependence of XEL Intensity on the Position





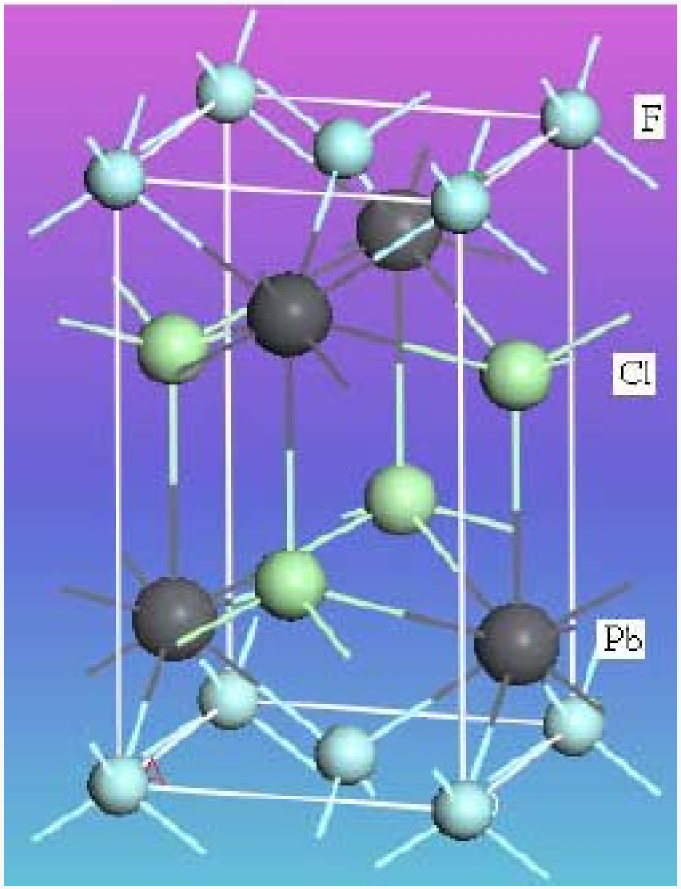


Distribution of Gd ions along the growth direction of PbF2 crystal

(■ tested value, • calculated value)

K~2

4. PbClF



D= 7.11g/cm^3

Melting point =600°C

Space group=P/4nmm

a=4.10Å;c= 7.22Å

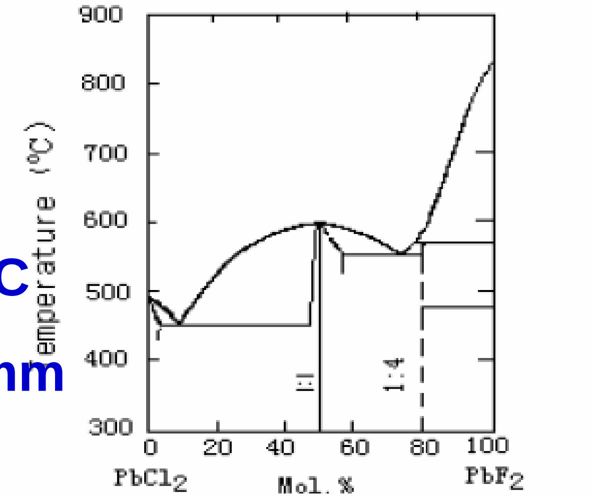


Figure 2.1 Phase relations in $PbCl_2$-PbF_2 system

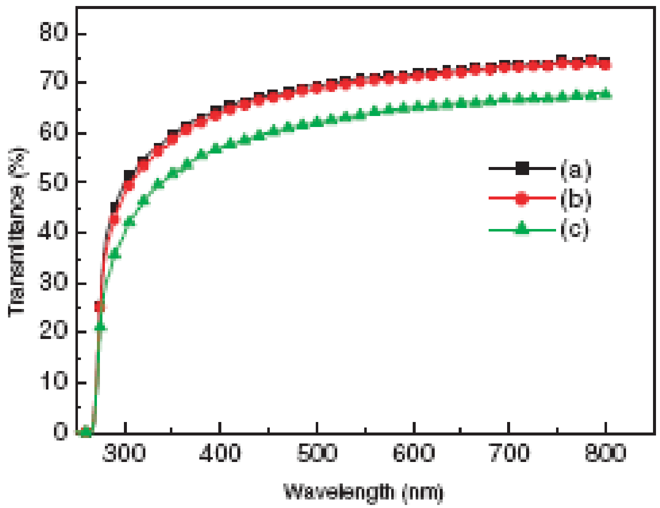
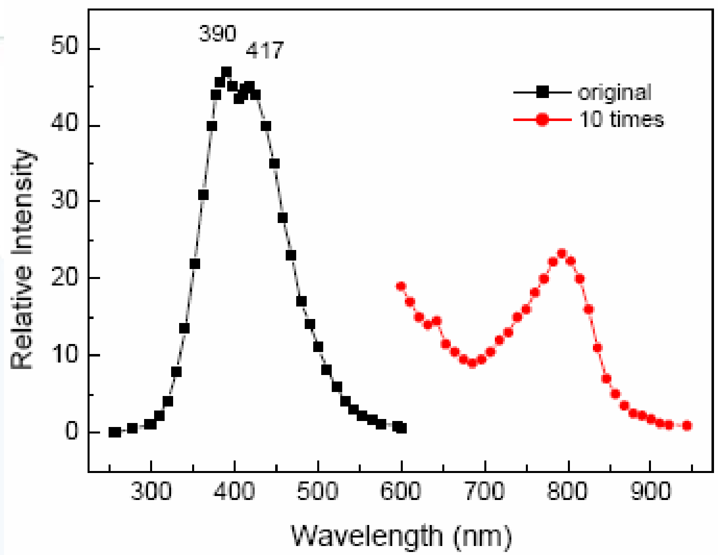


Figure 7. Transmittance curves of PbFCl crystal in 1 mm thickness along the [001] direction: (a) before irradiation, (b) after 35 rad h^{-1} × 28 h, (c) after about 500 rad h^{-1} × 48 h.



X-ray excited luminescence

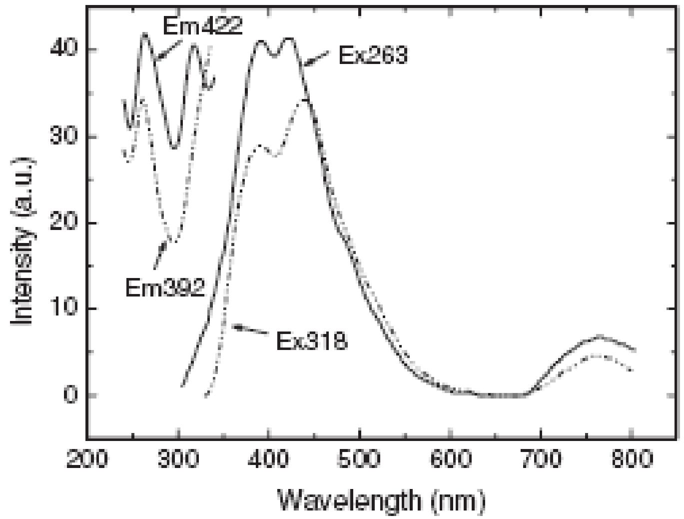


Figure 2. Excitation and emission spectra of PbFCl (T = 300 K)

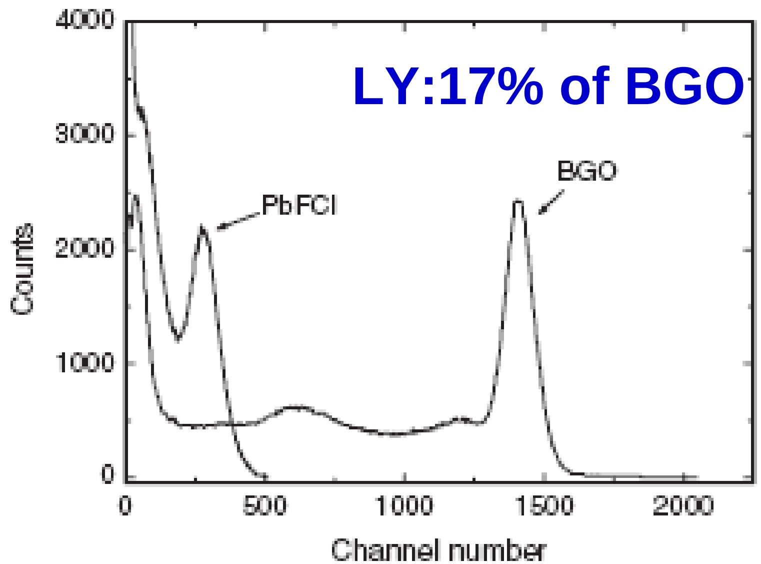


Figure 5. Pulse height spectra of PbFCl and BGO crystals (T = 300 K).

Summary

- Our modified non-vacuum Brdgman method is an effective technique to grow Halide crystals;
- Lead fluoride is proved to be an excellent Cherenkov radiation materials, but so far no scintillation light has been observed, even for doping samples;
- PbClF may be a promising candidate do meet the requirements for HHCal.