

The most versatile scintillation detector and its application in various fields

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Outline

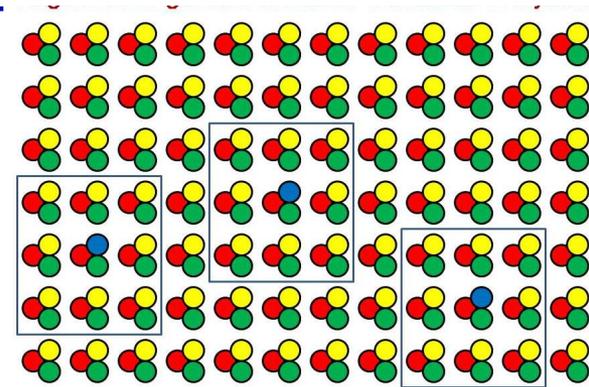
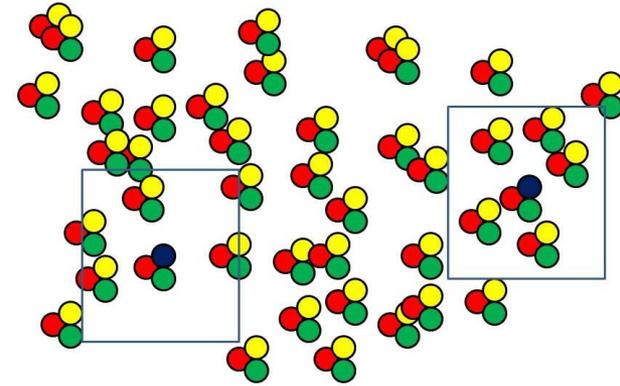
- Why Single Crystals, Growth & Challenges
- Synthesis and Systematic investigations
- Example :Ce doped GGAG
- Summary

Why Single crystals?

Unbroken lattice, No grain boundary

The best Combination of the following properties

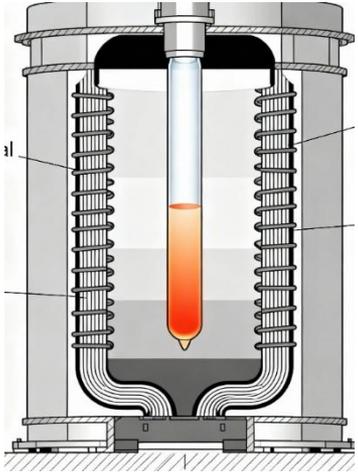
- High density
- Rich in electrons which interact with radiation
- Absence of grain boundaries
- Absence of size/structure distribution effect
- Broad transmission range
- Better mechanical and radiation hardness
- Uniformity
- Better energy proportionality and resolution



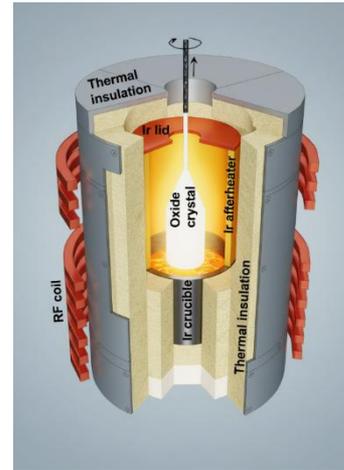
Choice of scintillator

- Application-Current or Pulse mode
- Type of radiation
- Energy of Radiation
- Count rate
- Experimental condition
- Requirement of size
- Cost

Growth of Single crystals by Melt



Bridgeman Technique & furnaces @ BARC



Czochralski Technique & pullers @ BARC

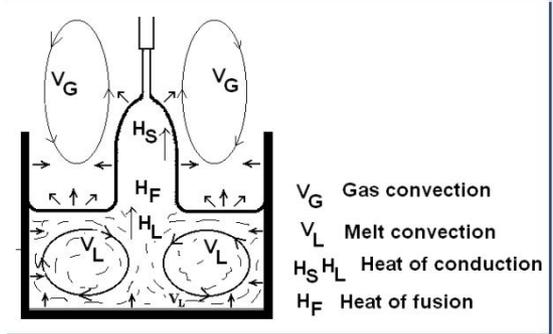


Challenges in crystal growth

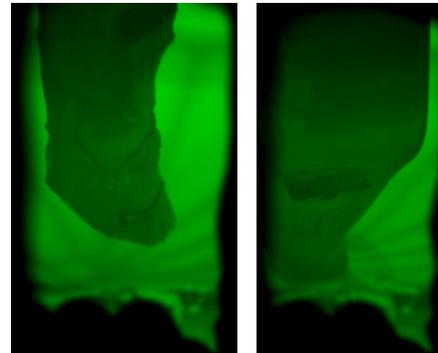
- Optimization of growth parameters
- Thermal behaviour --- evaporative losses, supercooling, Decomposition etc.
- Cracking --- Cleavage planes
- Controlled by power only
- Segregation of dopants
- Effect of ambient – Defects
- Yield
- Unpredictable



Deposition of Ga₂O₃



Heat flow and convective currents during a Czocharalski growth process

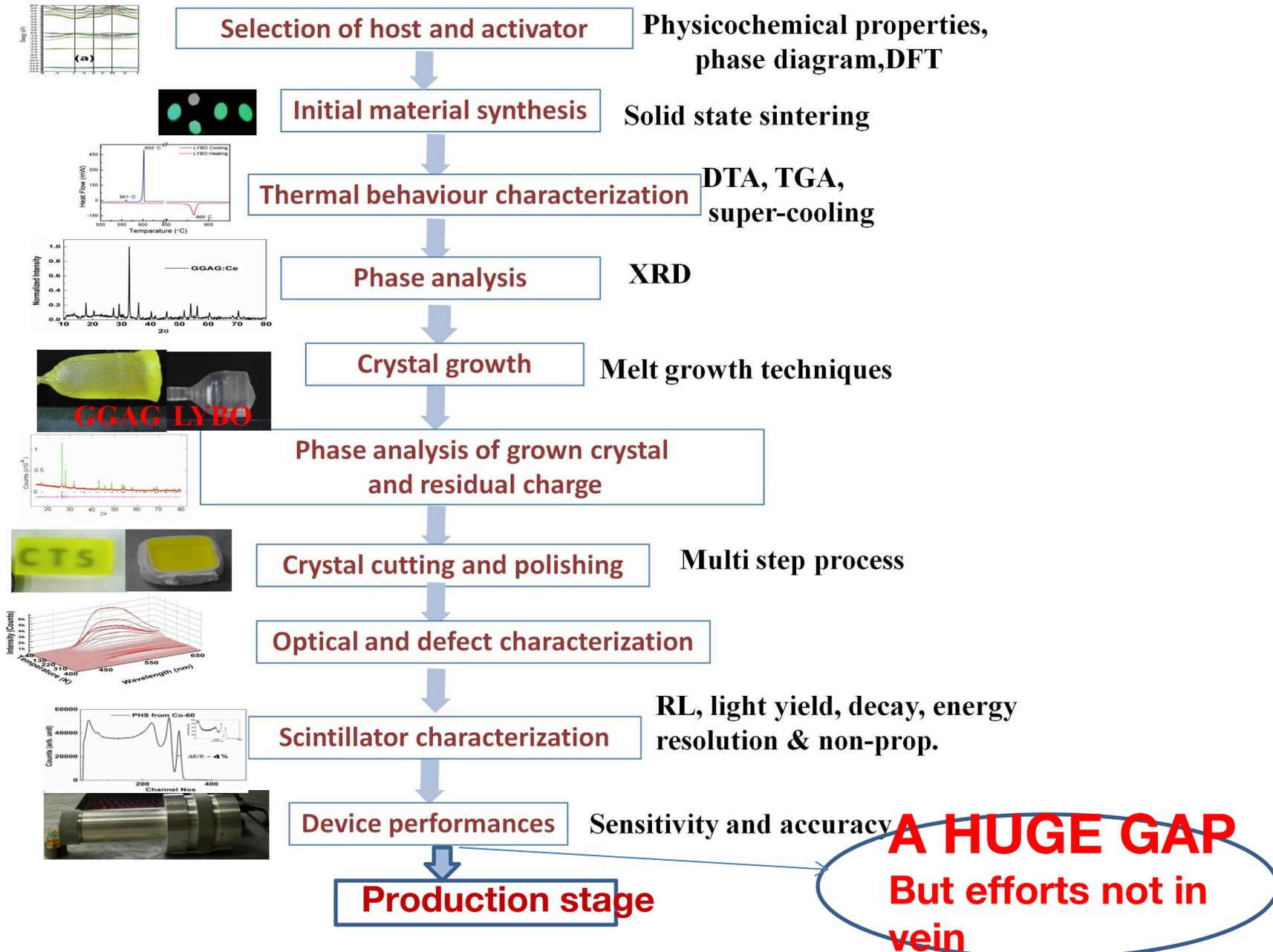


Heat flow pattern captured during Czocharalski growth process of GGAG



Result of imbalance

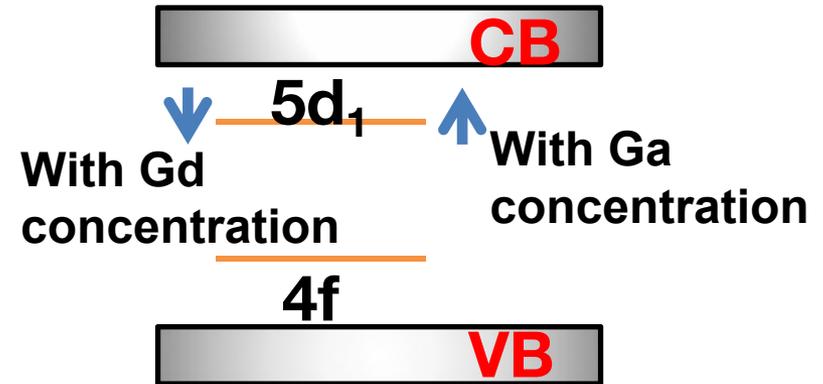
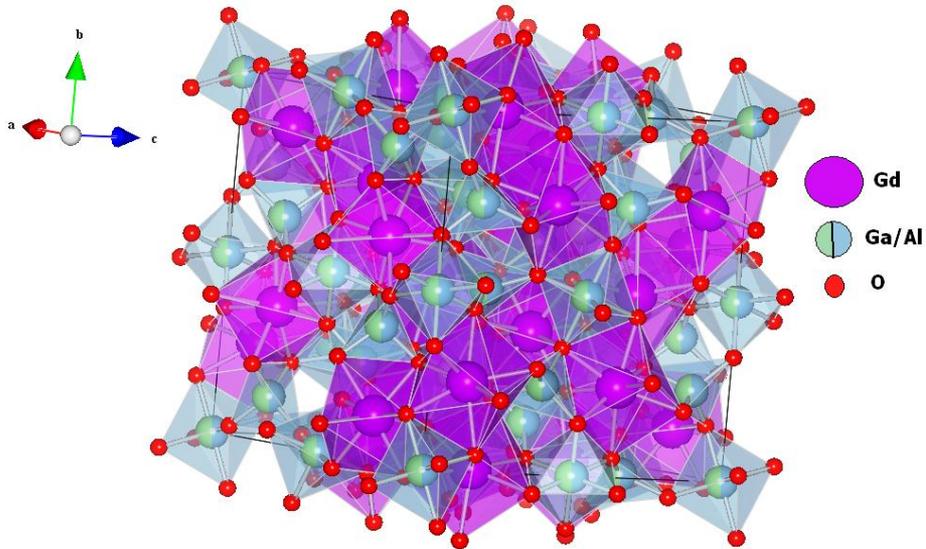
A journey of systematic investigations towards production



**Ce doped $\text{Gd}_3\text{Ga}_3\text{Al}_2\text{O}_{12}$
Basics to Device**

Band gap engineering

Ce doped $R_3Ga_xAl_{5-x}O_{12}$ (R=Lu, Gd, Sc, Y, La)

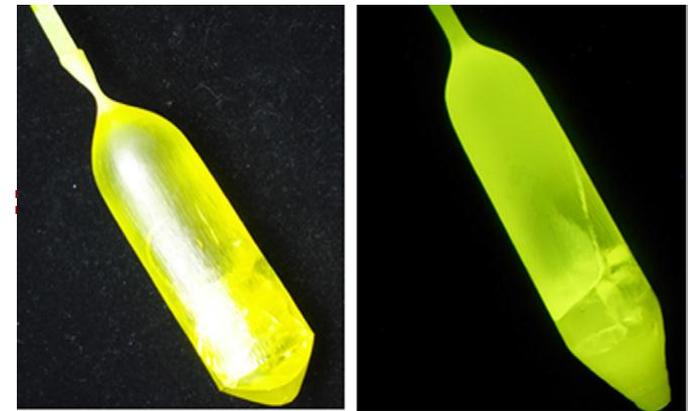


➤ Local re-adjustment of crystal field around the activator site

❖ **The best combination for x**
 $Gd_3Ga_3Al_2O_{12}$ (GGAG)

$Y_3Al_5O_{12}$: 8000 photons/MeV

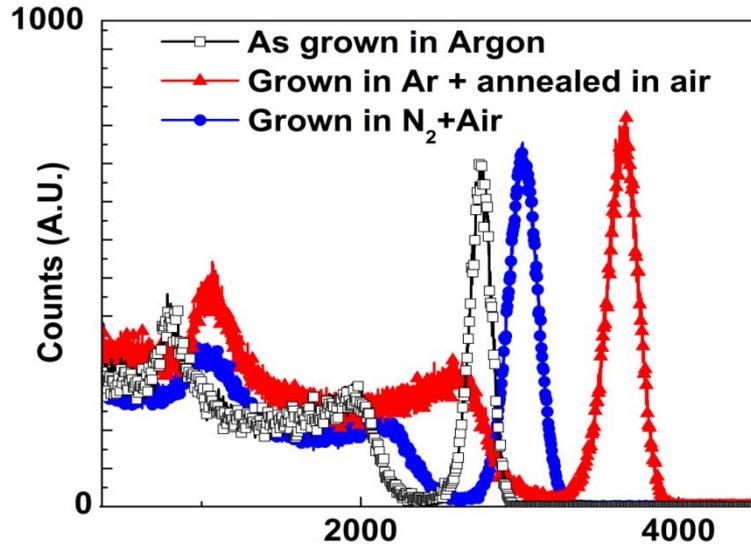
$Gd_3Ga_3Al_2O_{12}$: 60000 photons/MeV



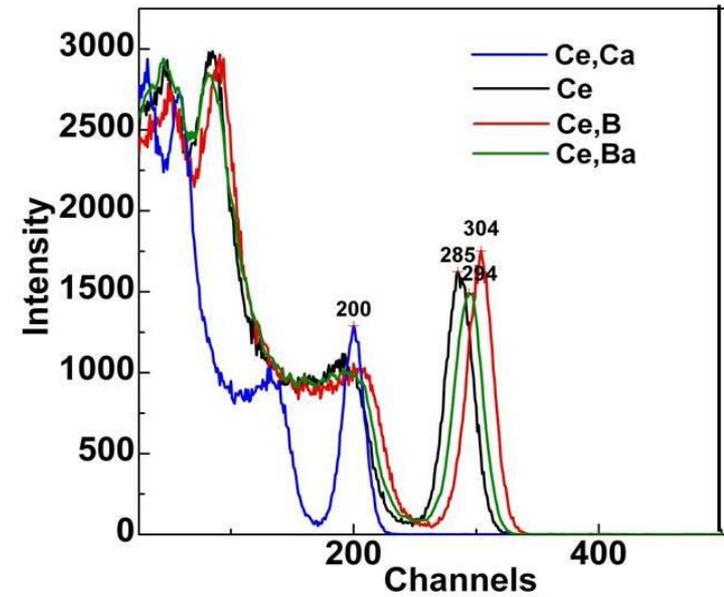
As grown

UV illuminated

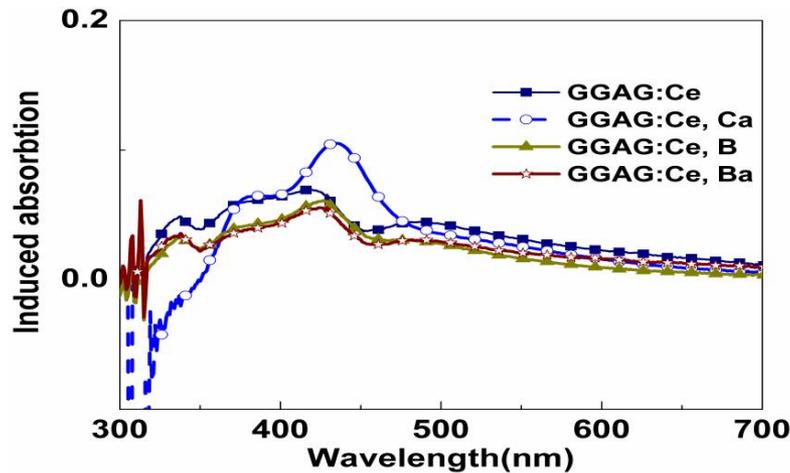
Material (defect) Engineering: Further improvements



Effect of after growth annealing on scintillation



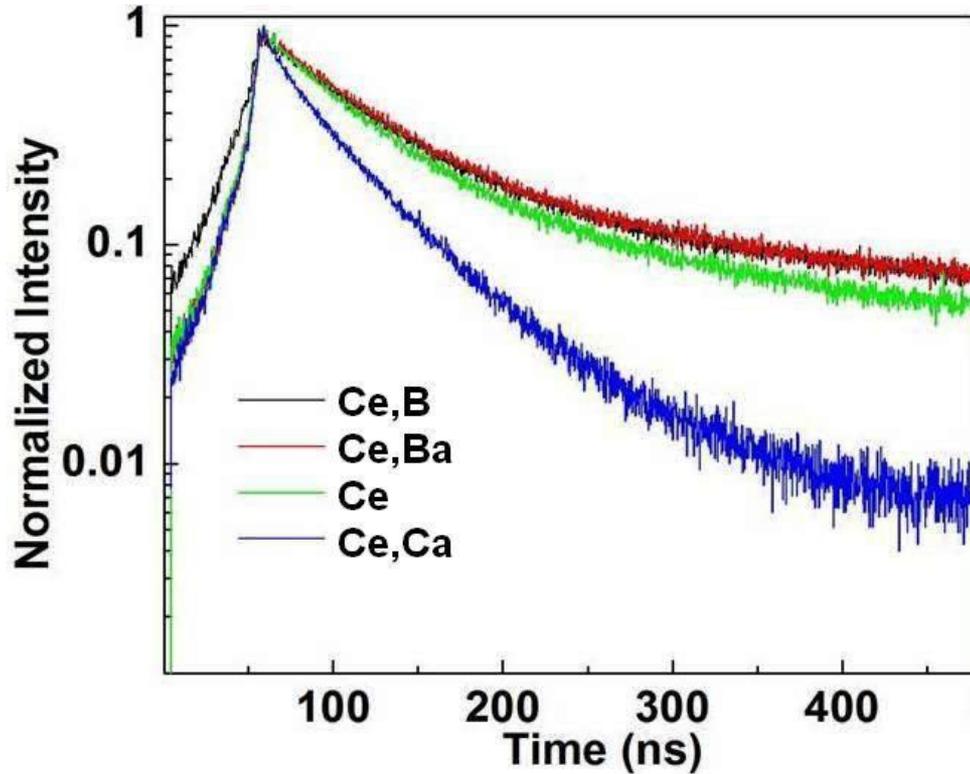
Effect of Co-doping on Light yield



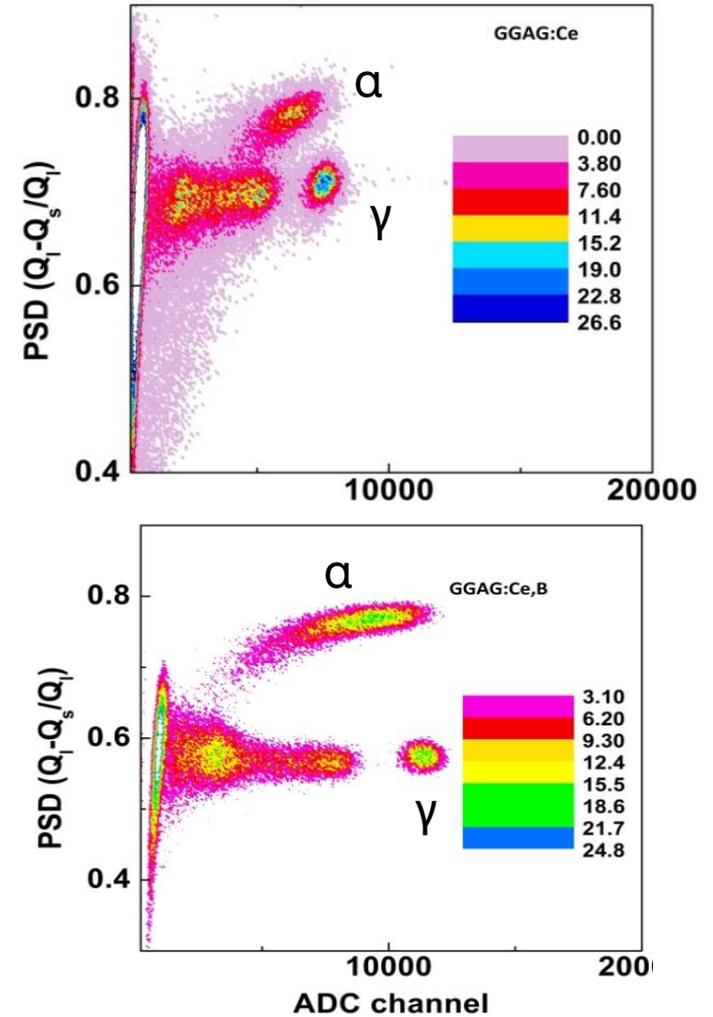
Effect of Co-doping on Radiation hardness

Patented in US , Japan, Germany, China, Europe and PCT

Effect of Co-doping



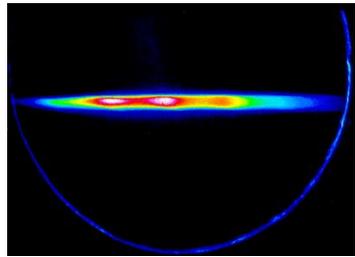
Effect of Co-doping on decay time



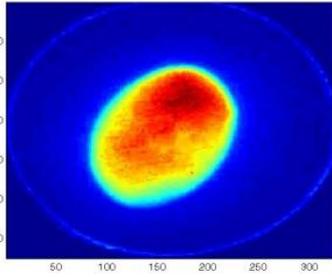
Pulse shape Discrimination

Most Versatile performance

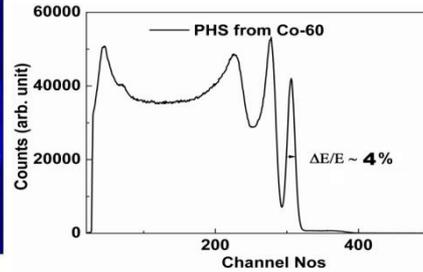
Devices using GGAG:Ce; A versatile scintillator



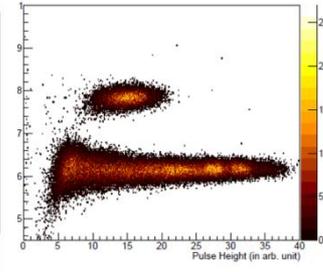
X-ray



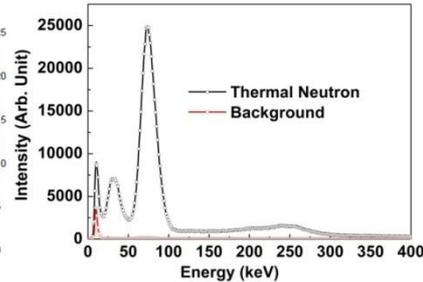
Electron



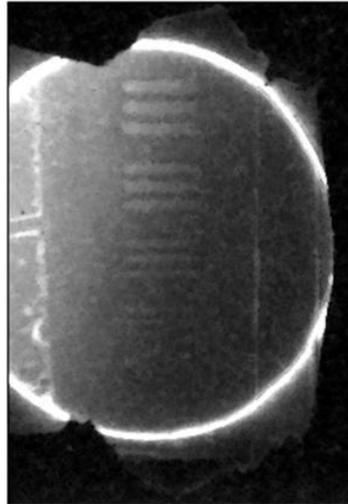
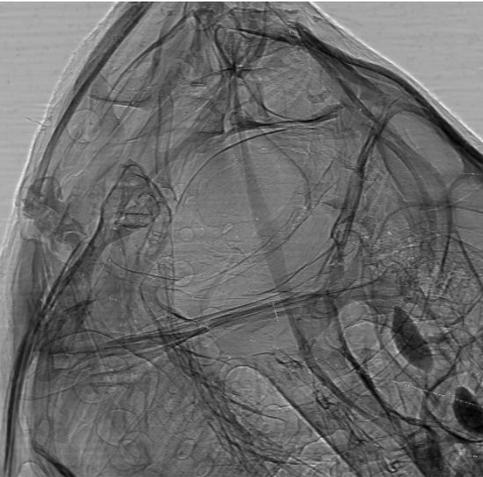
Gamma



Charged particle

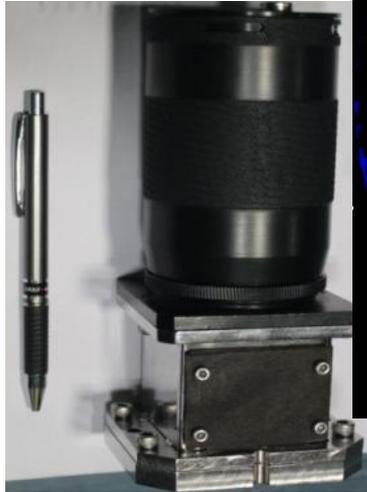


Neutrons

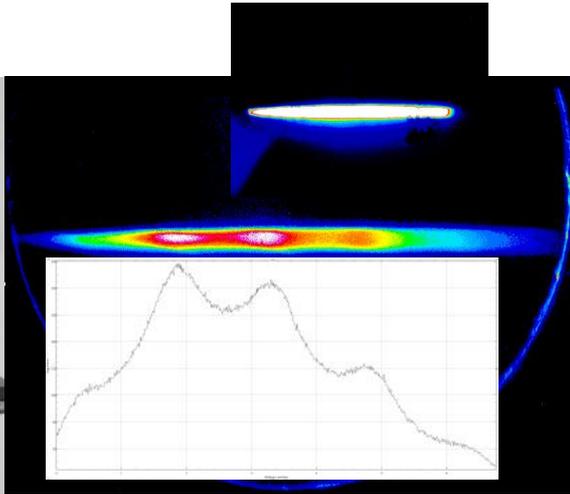


Significant co-ordinated combined effort behind each figure

X-ray detector



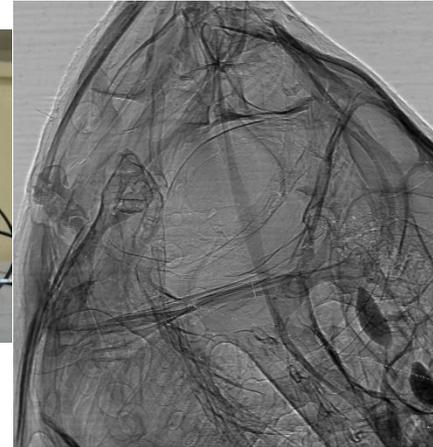
X-ray camera based on GGAG crystal installed at Indus-2 beam line



X-ray beam profile at synchrotron beam line using Single crystal and saturated profile using phosphor

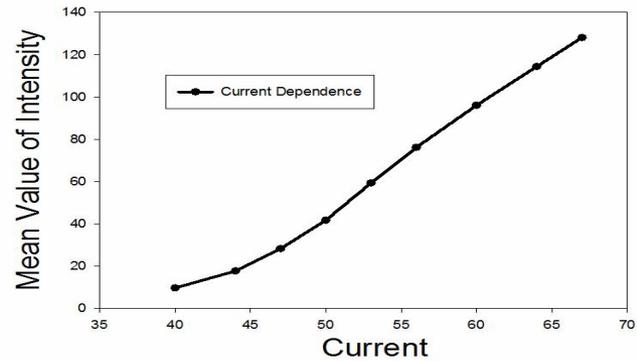
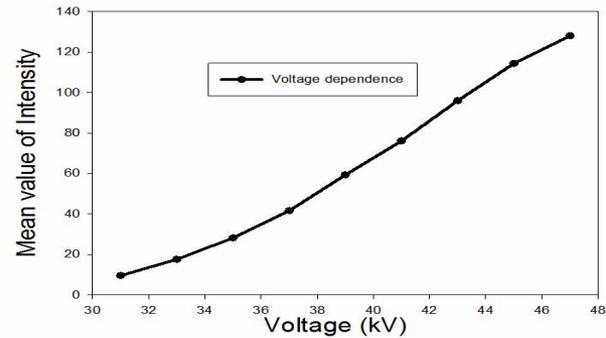
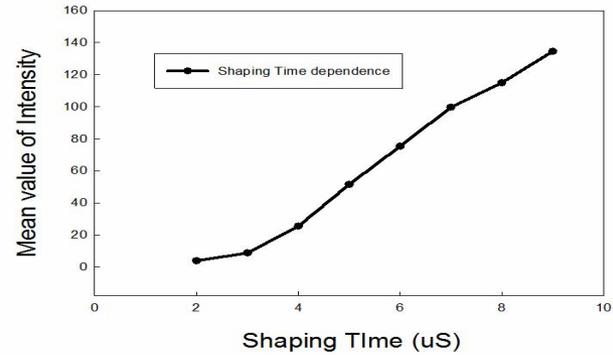
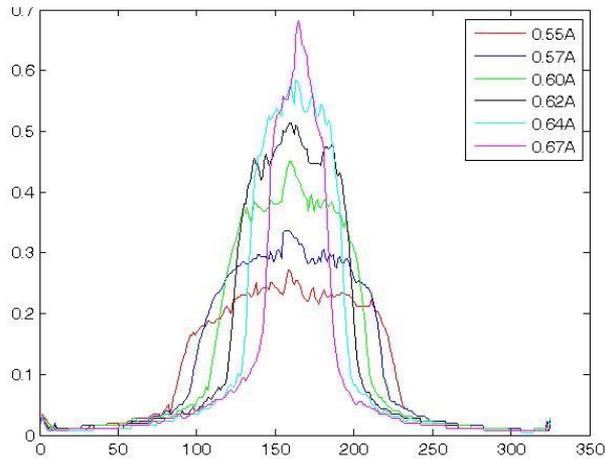
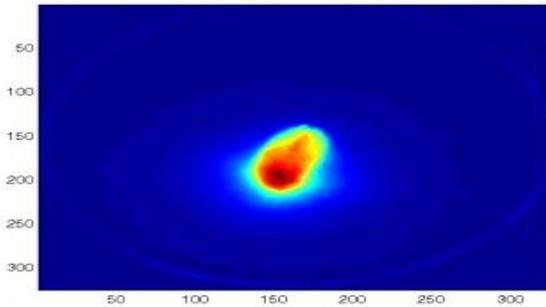
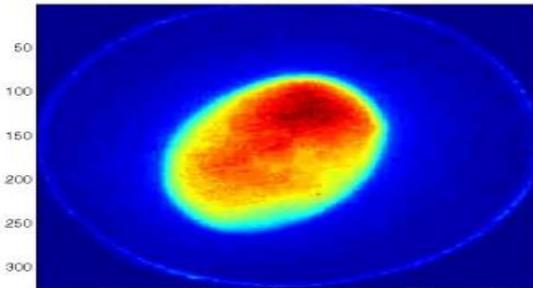


Detector measuring for X-rays time profile of accelerators at APPD



X-ray micro tomography of zebra fish head using GGAG crystal

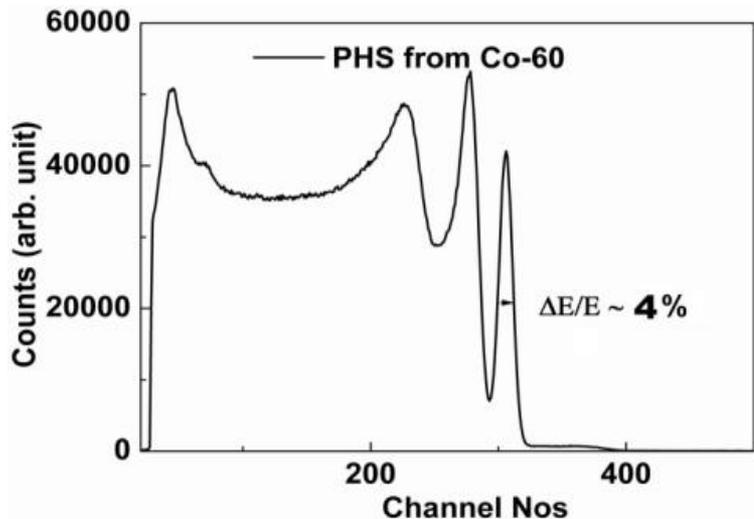
Electron beam profile monitor



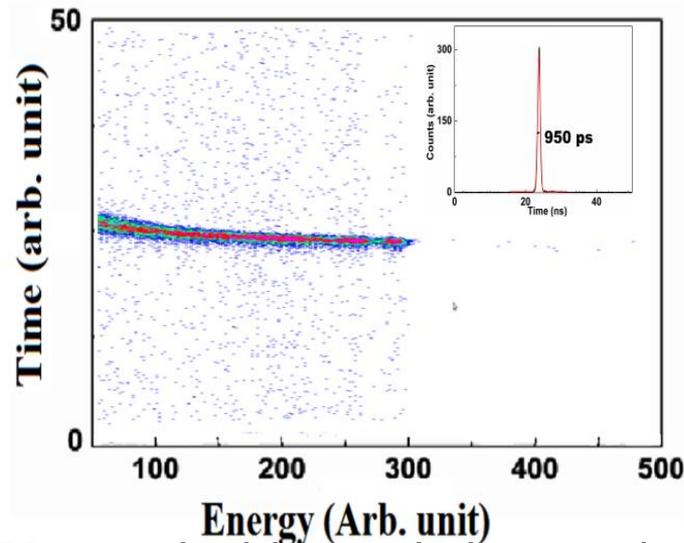
Effect of shaping time, voltage and current (No saturation @ 70 kV & 0.65 A)

Gamma detector

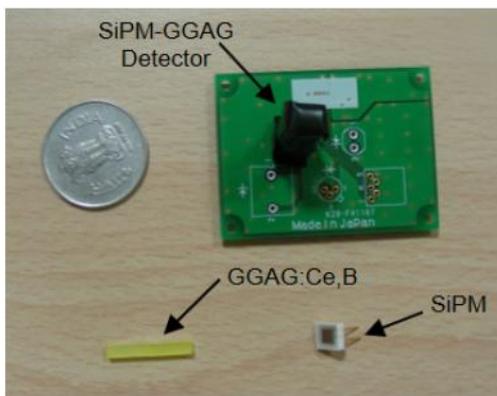
- High density, Fast decay



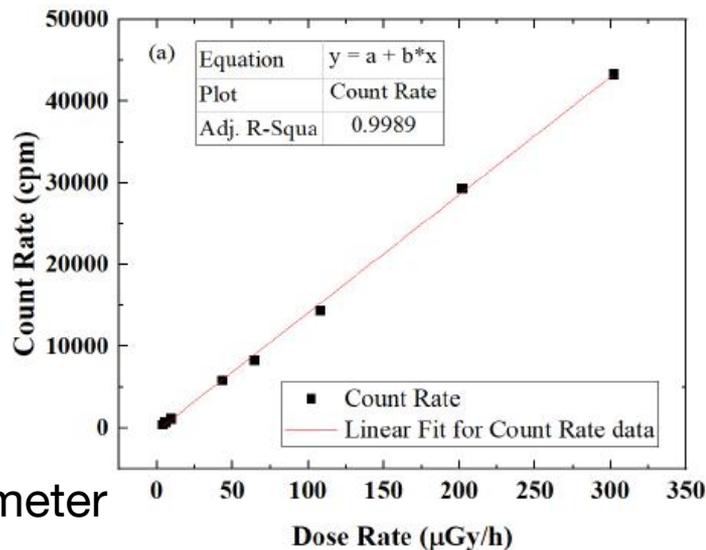
Pulse height spectrum measured with Co-60 source



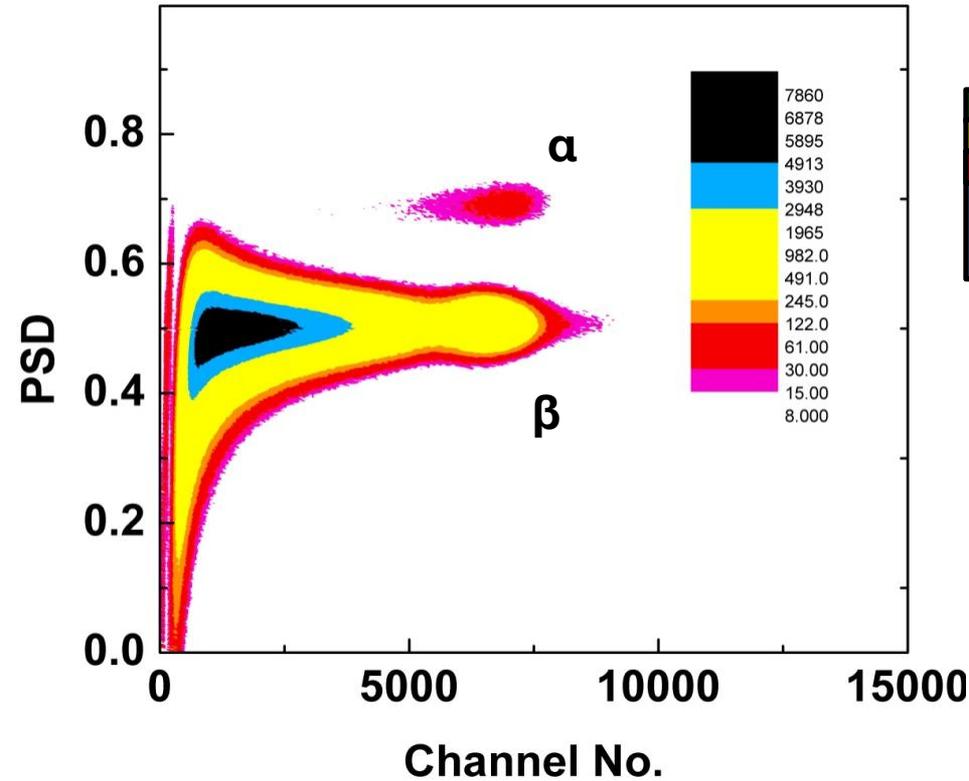
~ 850 ps coincidence timing resolution (For PET detectors)



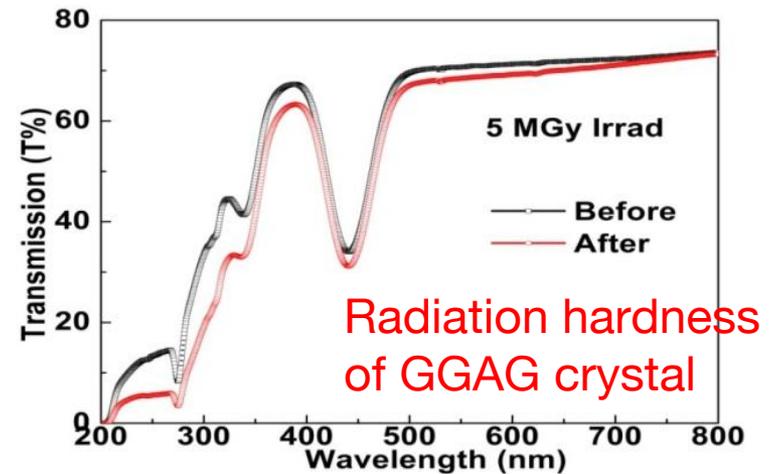
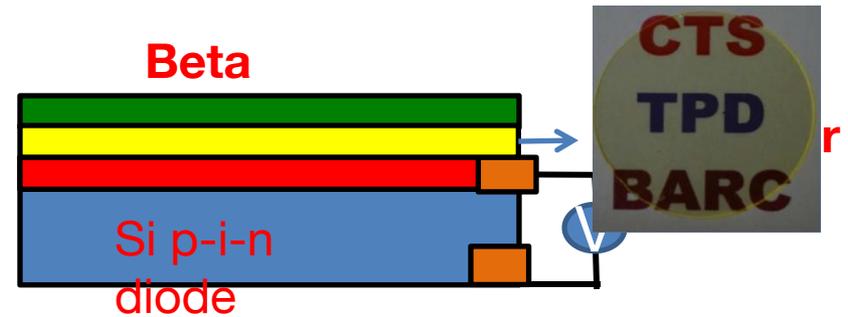
Compact environmental dosimeter



Charged particles

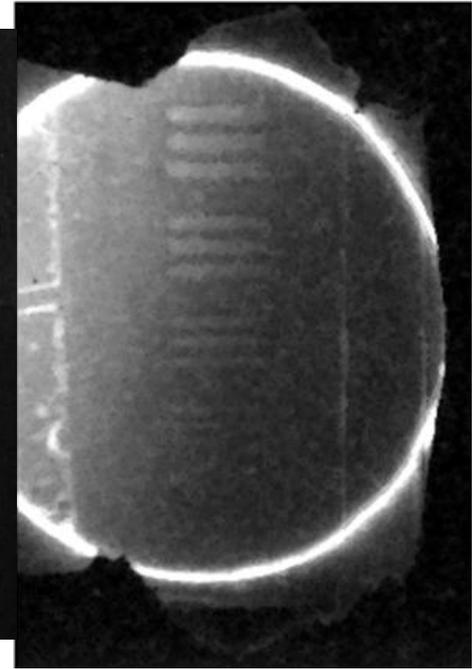
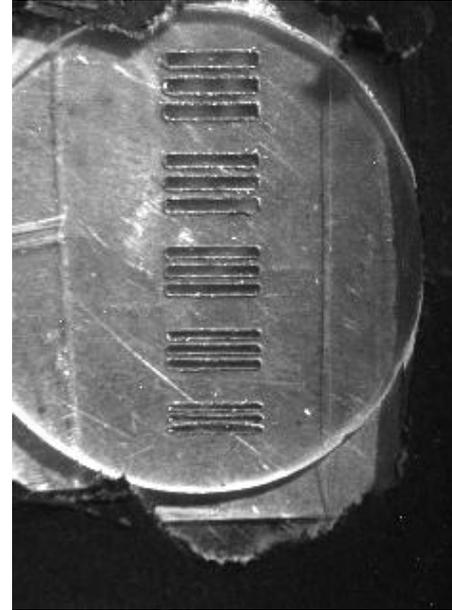
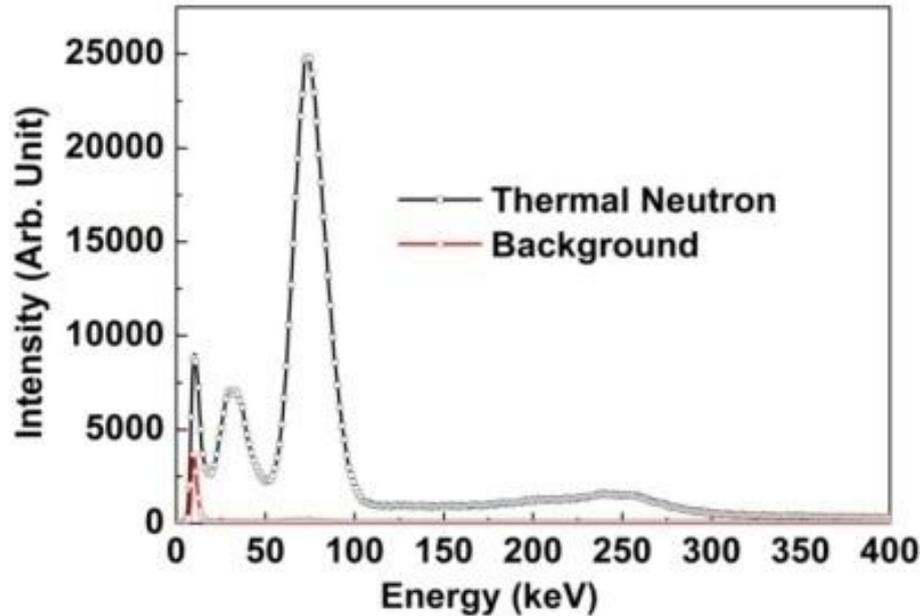


Discriminating 1:10E6 alpha contamination in beta source based on pulse shape discrimination



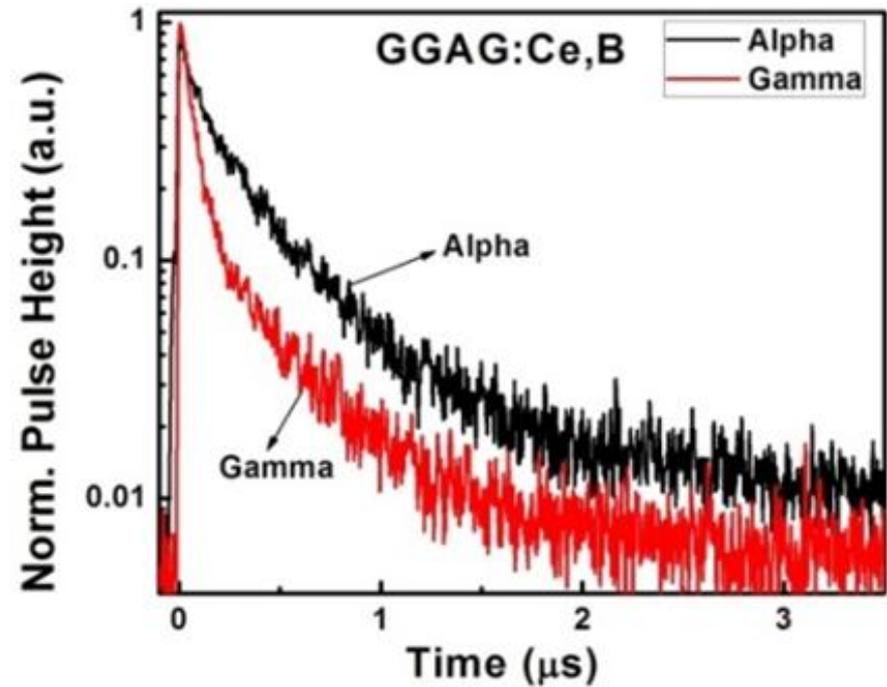
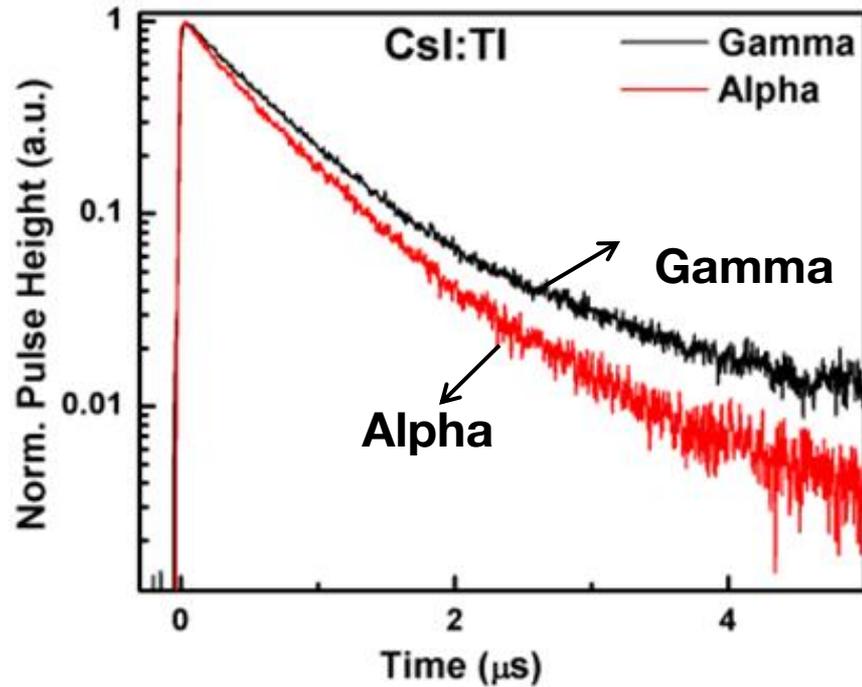
Development of radiation resistant beta-voltaic battery using GGAG scintillator and high energy beta source

Thermal neutron detection



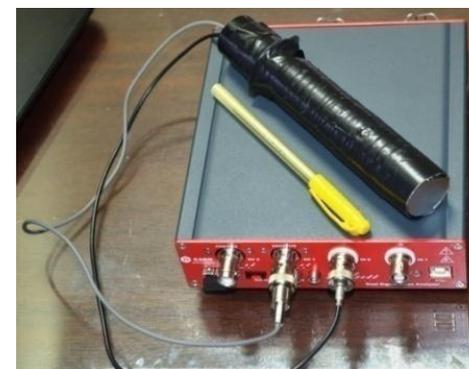
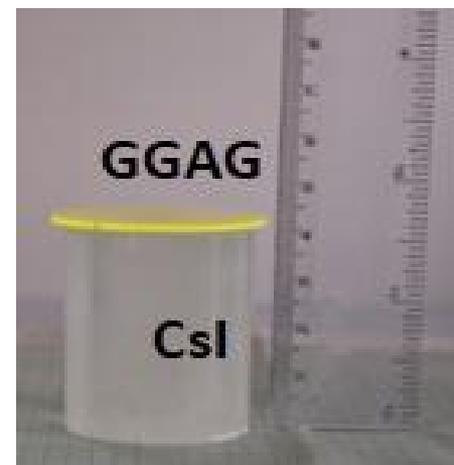
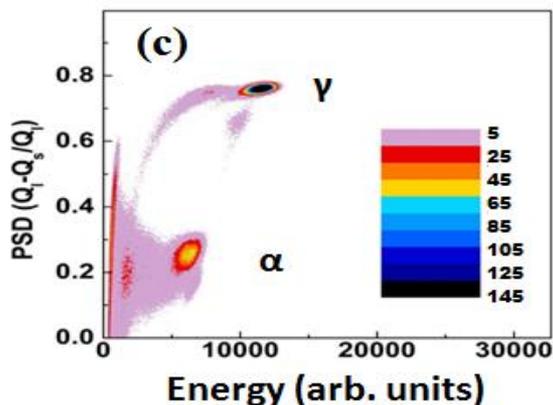
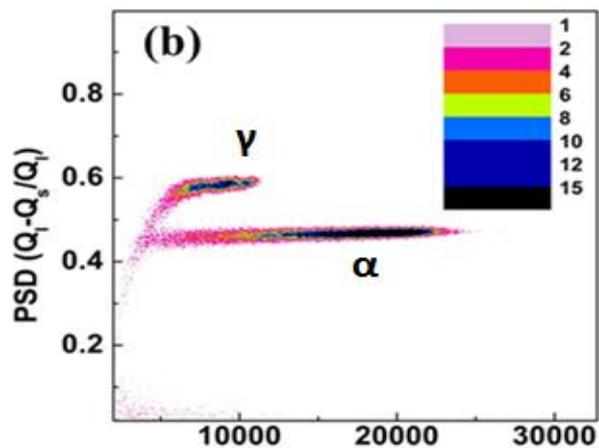
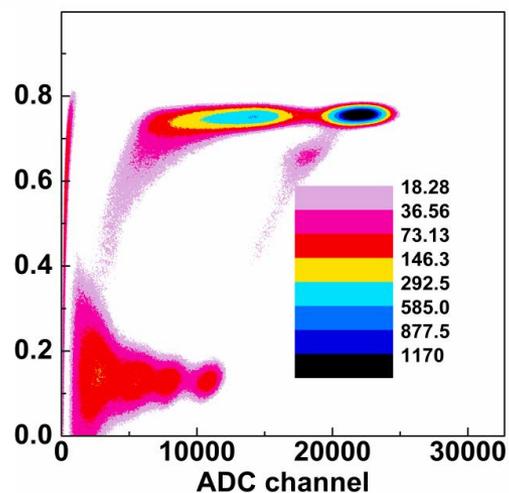
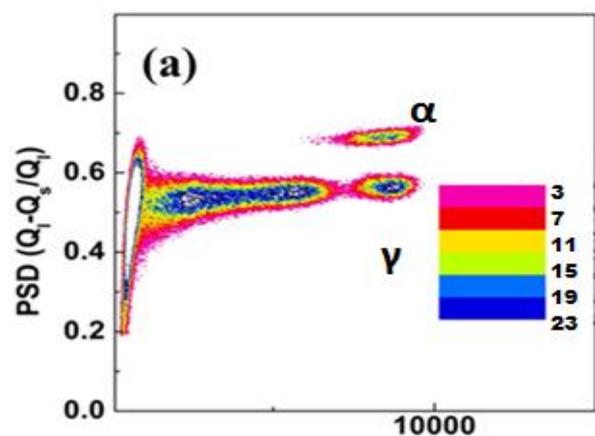
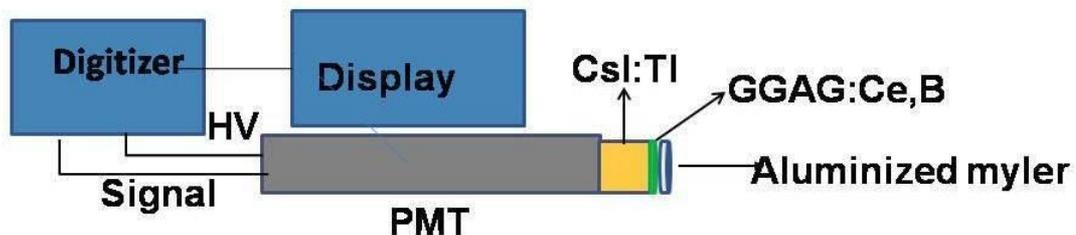
- stopping efficiency $\sim 100\%$ in few micron crystal only
- Detection efficiency by integrating 35 and 77 keV peak $\sim 80\%$

Unusual excitation density dependence



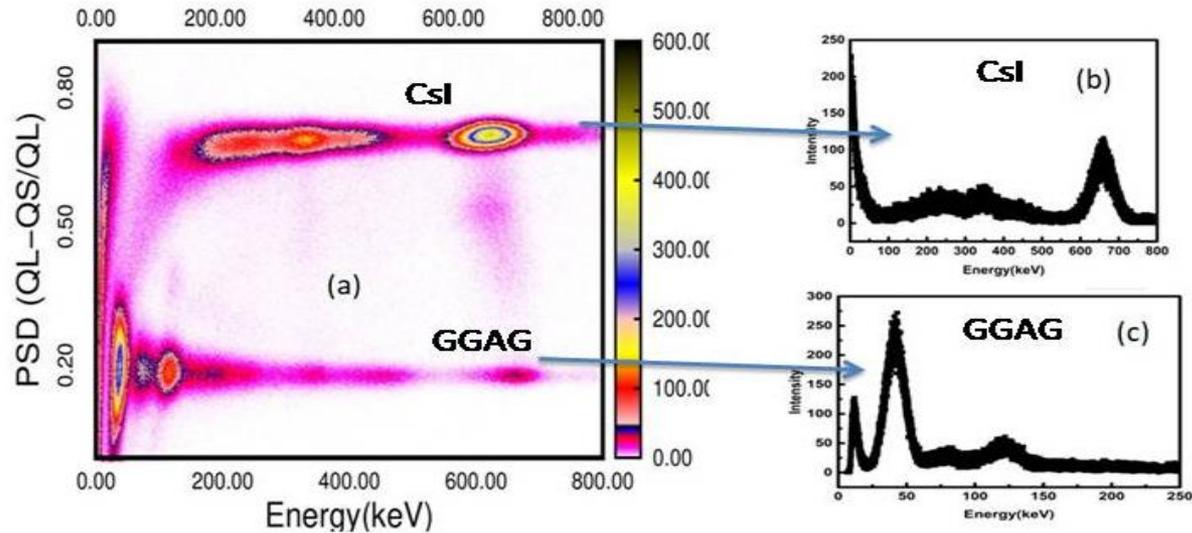
- Opposite behavior and slower decay times for alpha in GGAG can not be explained with the available quenching mechanism.

A novel versatile phoswich detector

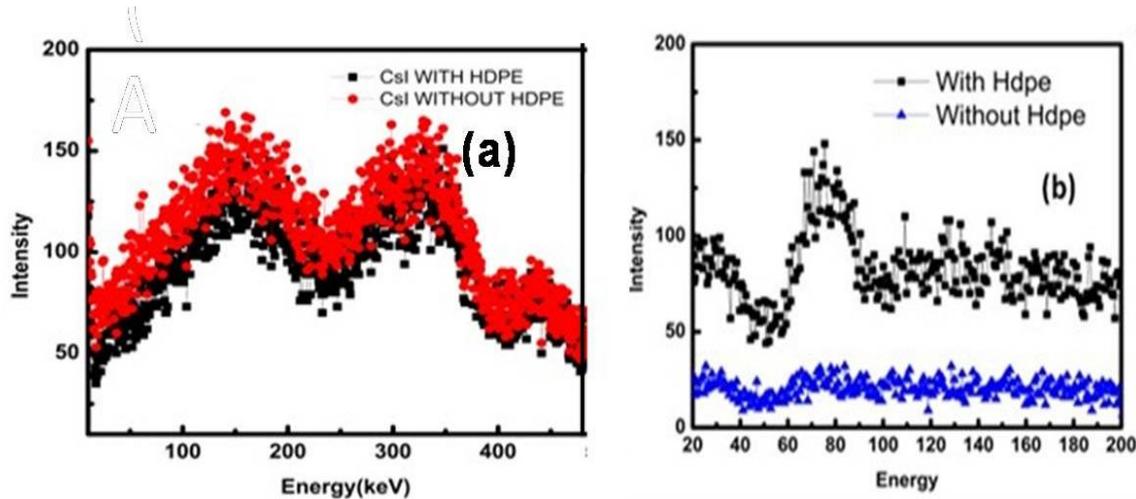


US Patent 16/358427

SNM assaying using Phoswich detector



Detection of low energy gamma in presence of high energies



Detection of thermal neutrons simultaneously using HDPE

Summary

- ❑ Aim to replace NaI or CsI : NO
- ❑ Current & Future; Very specialized scintillator
- ❑ Combined efforts
- ❑ Our role as scintillator community to find out the most appropriate solution
- ❑ End User role to work as a collaborator
- ❑ Industry role for scaling up – Incubation and ToT

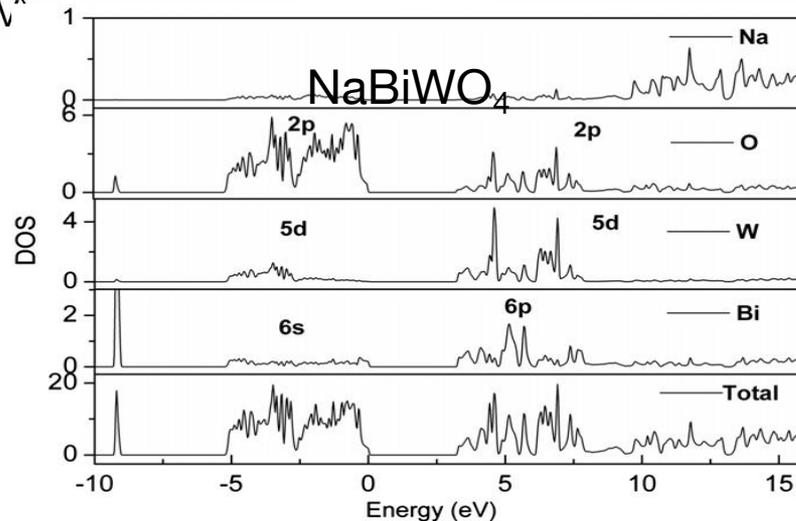
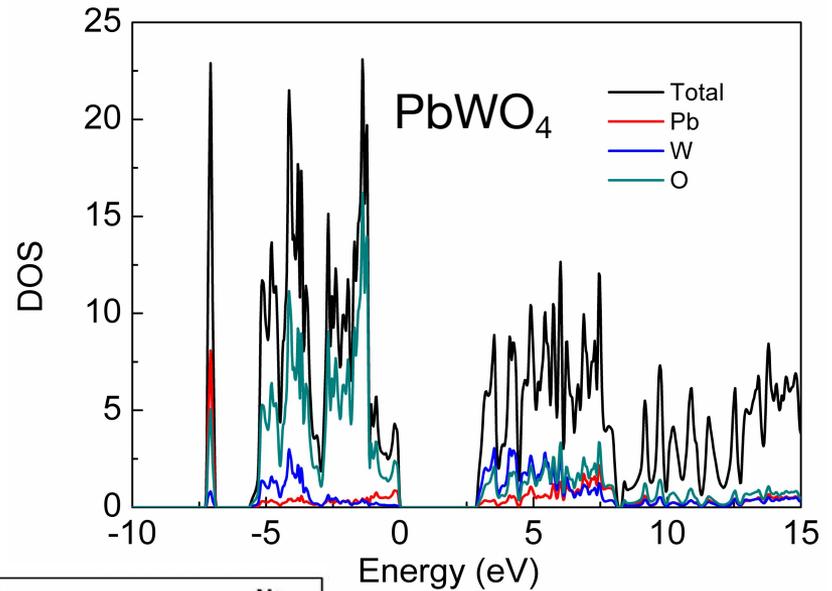
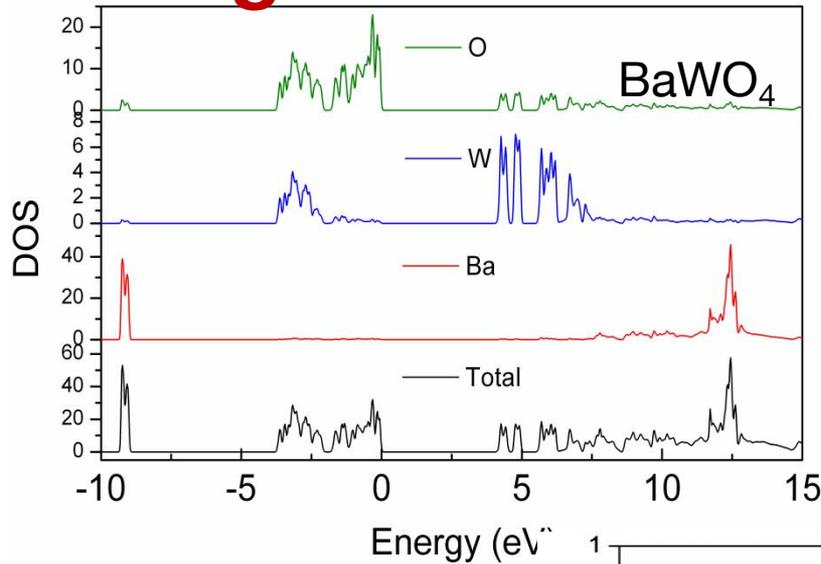
Acknowledgement

- **Colleagues from TPD**
- **Collaborators and End-users**



- Back up

DFT Calculated electronic properties of Tungstates



➤ BaWO₄ as good Cherenkov radiator

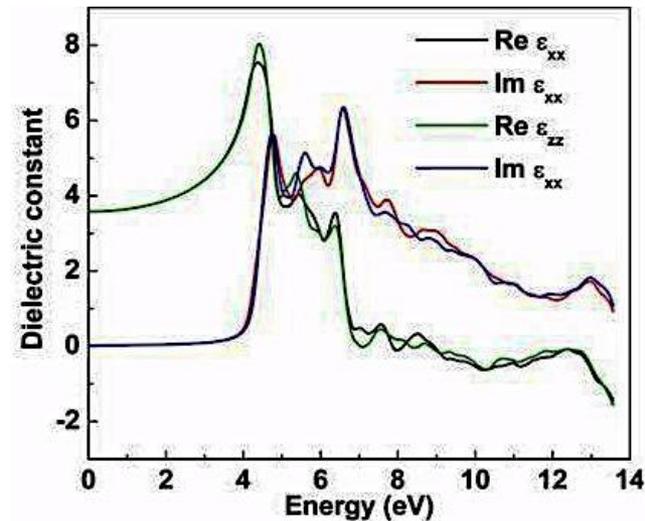
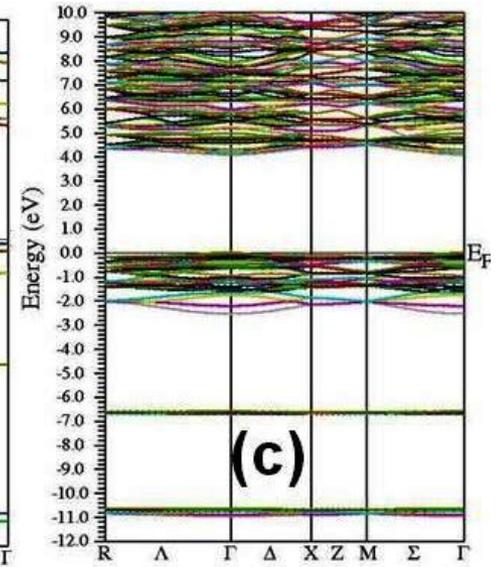
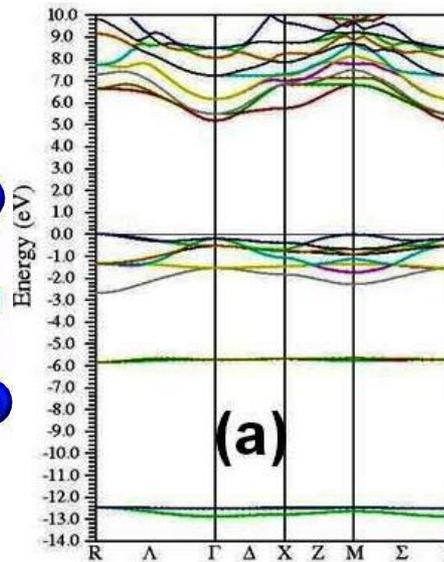
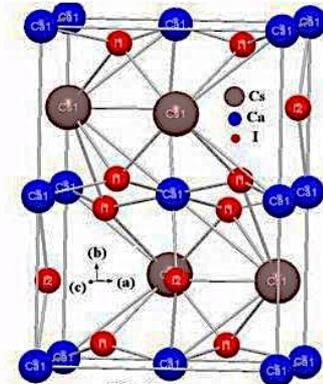
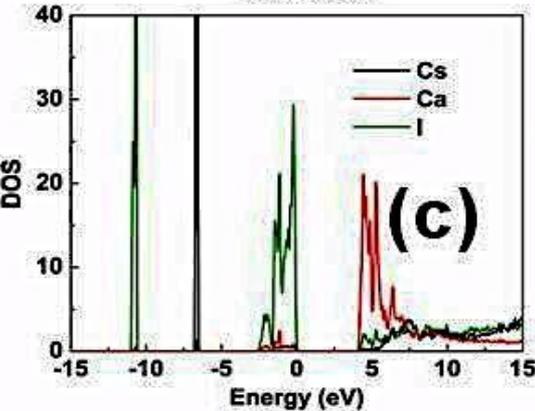
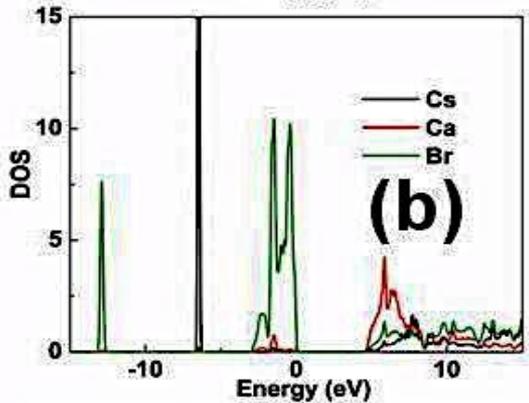
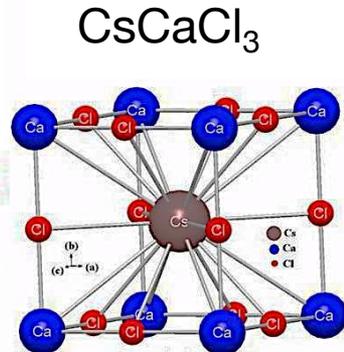
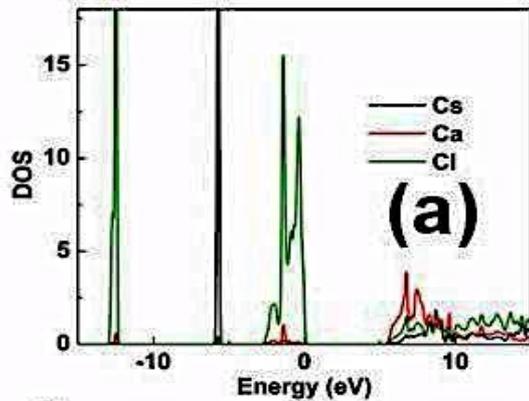
M. Tyagi et al. *Journal of Luminescence*, 132 (2012) 41

M. Tyagi et al. *Physica B* 40, (2010), 3267

M. Tyagi et al. *Physica B* 405, (2010), 4530

Metal halides

Density of states and band structure

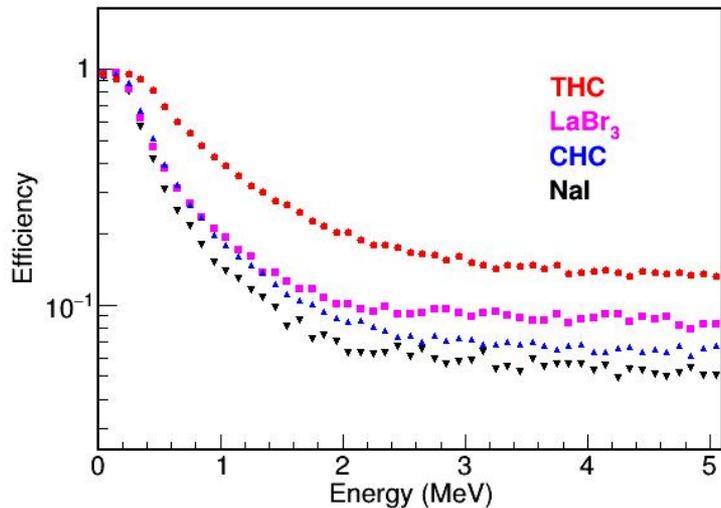


Isotropic dielectric constant of CsCaI3

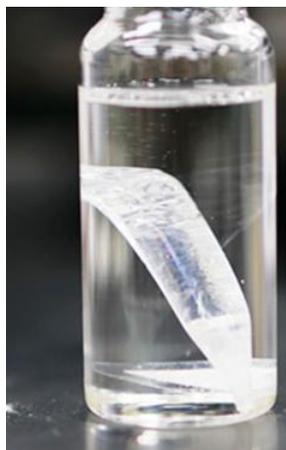
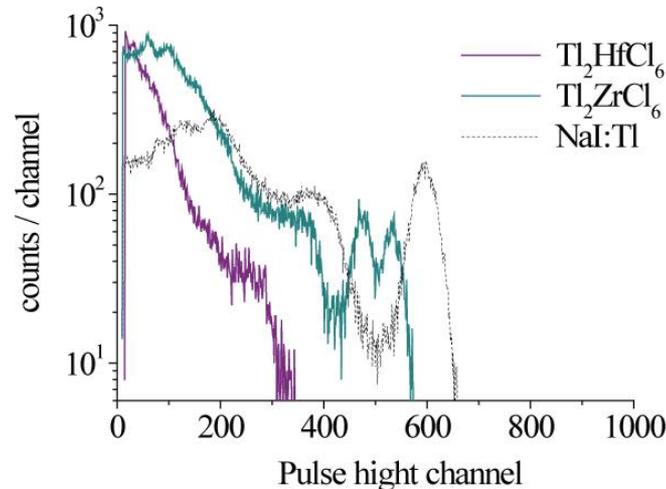
Prediction of Light yield (thermalization length), proportionality, Cross-luminescence and OTC

Improvement in Tl_2HfCl_6 after impurity refinement

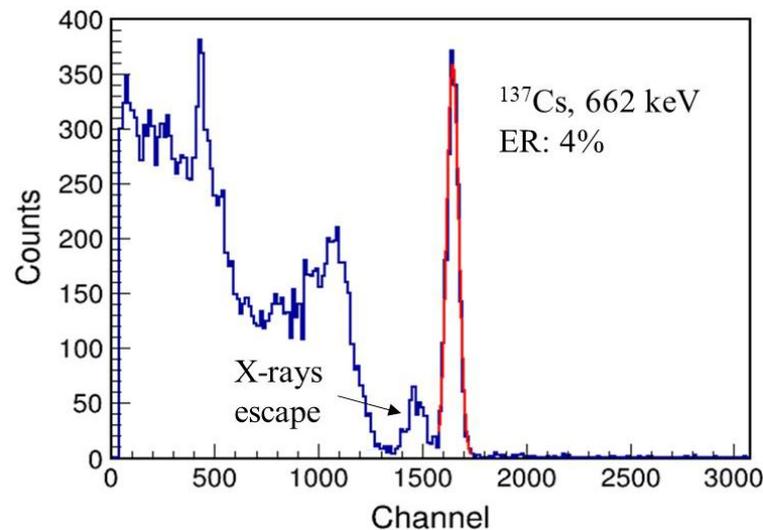
- Very high $Z_{\text{eff}} - 72$
- Rare event search of α -decay from ^{174}Hf with $Q_\alpha = 2.5 \text{ MeV}$



Detection efficiency comparison



Improvement of crystal quality after refinement



Excellent improvement of earlier reported energy resolution

M Tyagi et al CrystEngCom (2019) communicated