UNIVERSITY OF BIRMINGHAM

12th International Conference on
POSITION SENSITIVE DETECTORS

Laboratory of luminescent and detector materials.
NRC "Kurchatov institute"

NRC "Kurchatov institute" - IREA

Composite GYAGG-based scintillation screen for neutron detection

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4 - Atomtex SPE, Minsk

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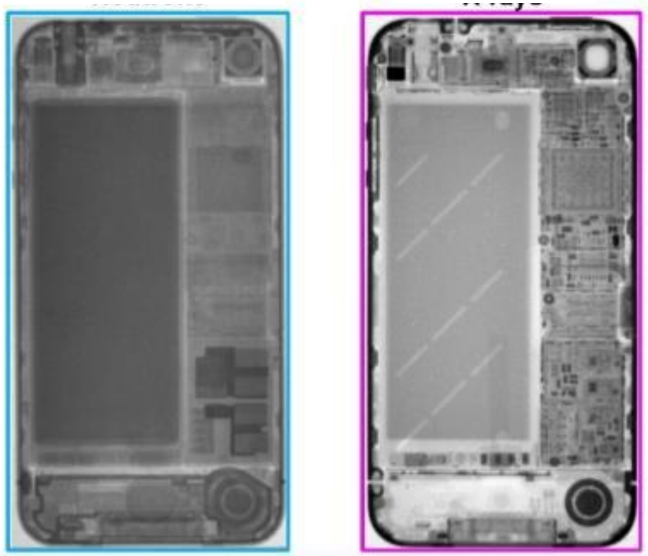
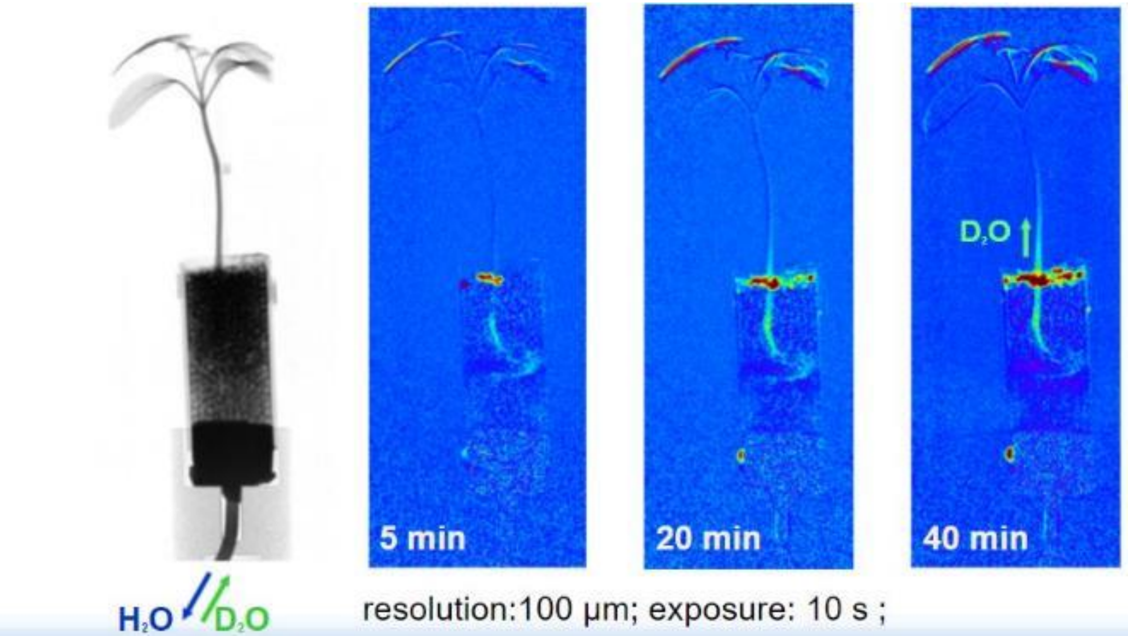
Scintillation screens in neutron imaging

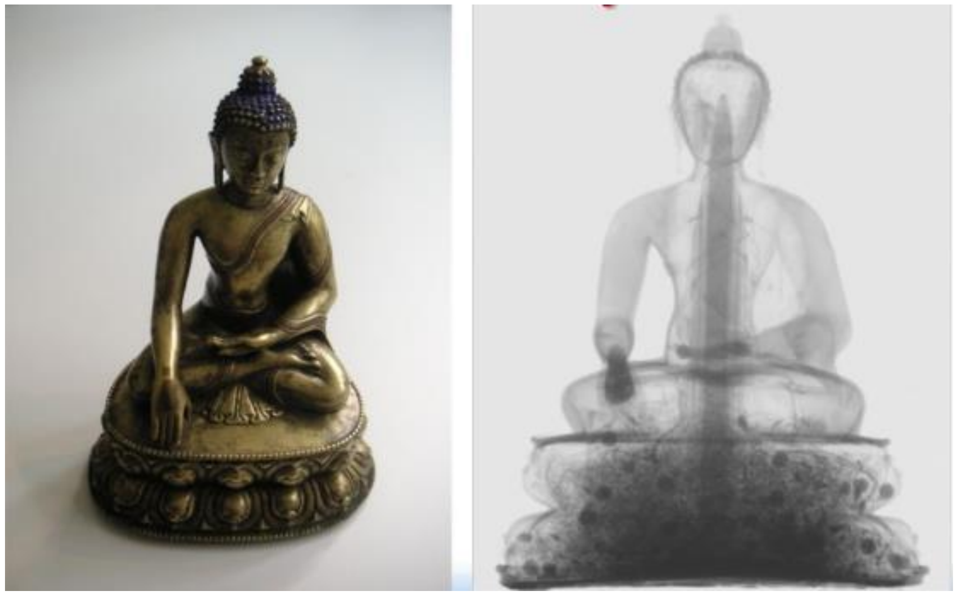
Neutron radiography and tomography are non-destructive research methods.

Images contrast is complementary to x-ray radiography

Neutrons **X-rays**

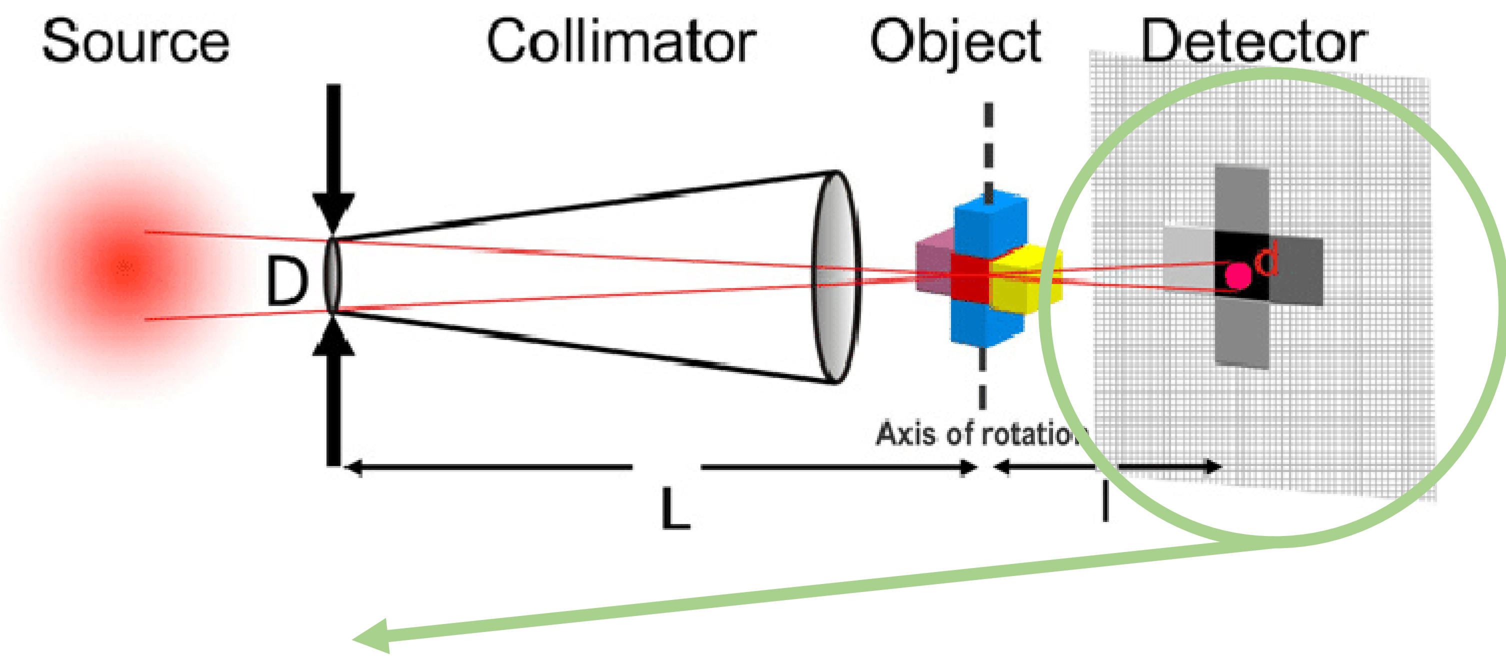


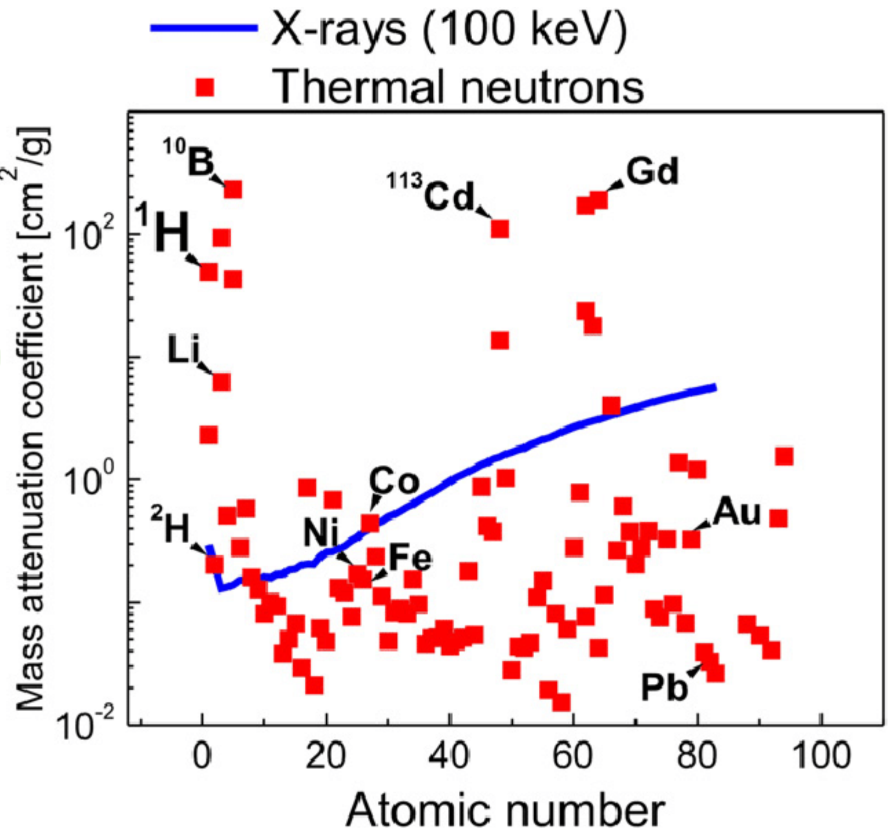




Images from: IAEA Neutron Imaging training course

Principles of neutron imaging





Detector - Scintillation screen

Fast decay time – fast readout

Bright – less exposure time

Good spatial resolution – more details are distinguishable

Images from: Strobl, Markus & Manke, Ingo & Kardjilov, Nikolay & Hilger, André & Dawson, M. & Banhart, John. (2009). TOPICAL REVIEW: Advances in neutron radiography and tomography. Journal of Physics D-applied Physics - J PHYS-D-APPL PHYS. 42. 10.1088/0022-3727/42/24/243001.

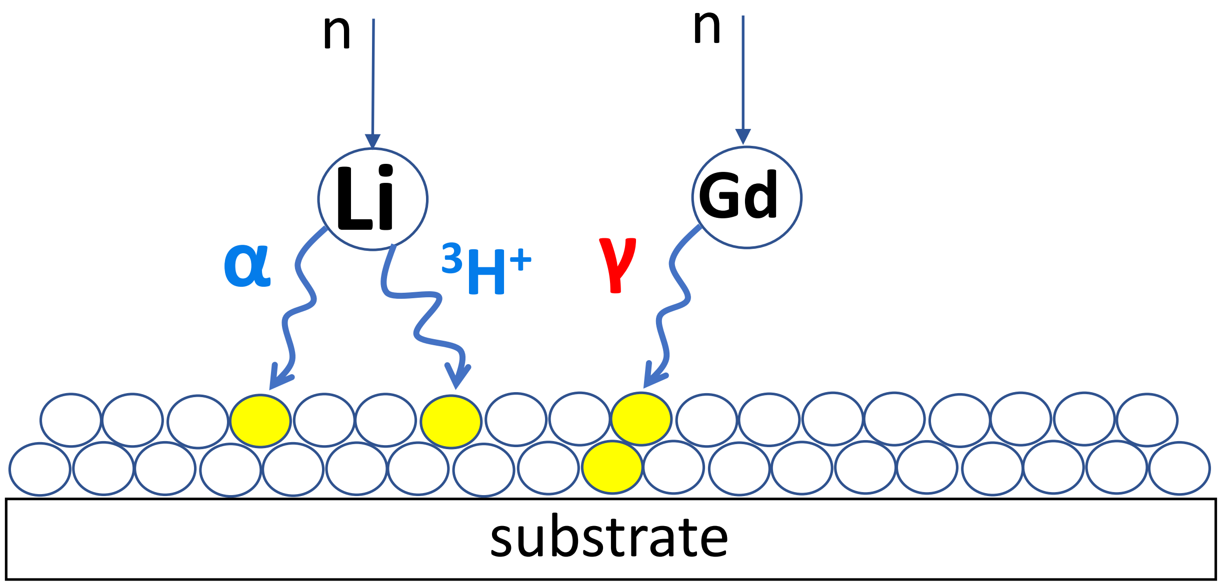
Scintillation screen composition

Neutron absorber (Li-containing)

$^{6}\mathbf{Li} + n \rightarrow \alpha + {}^{3}H^{+} + 4.8$ MeV (~940 barn)

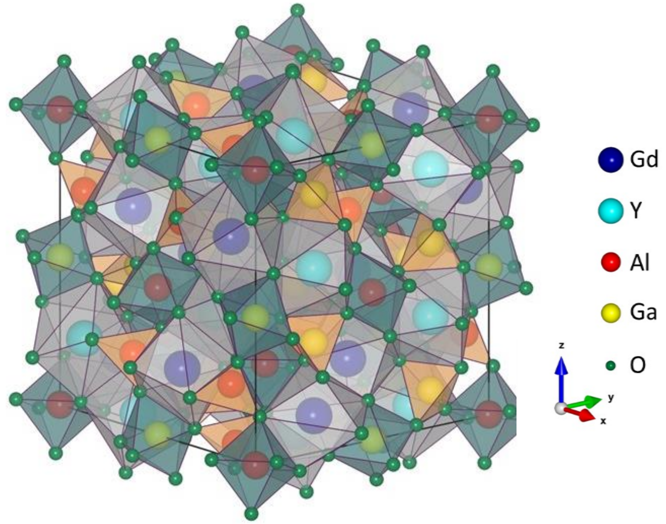
Scintillation pigment (Gd-containing)

Gd (natural) + n → Gd + γ + e^{-}_{conv} (~45 000 barn)



Scintillation pigments - GYAGG

$(Gd,Y)_3(Al,Ga)_5O_{12}$:Ln (Ln = Ce, Tb)



Scintillator	ρ, g/cm³	LY, ph/MeV	τ_{sc}, ns	λ_{max}, nm
$Gd_3Al_2Ga_3O_{12}$:Ce	6.67	40 000	~60	520
$Gd_{1.2}Y_{1.8}Al_2Ga_3O_{12}$:Ce	~6	up to 60 000	~60	520
$Gd_{1.2}Y_{1.8}Al_2Ga_3O_{12}$:Tb	~6	~200 000	~3*10⁶	500, 550

See our article: *M.Korzhik el al. Journal of Luminescence, 234, 117933, (**2021**)*

Ce-doped — **Fast decay kinetics** ⇒ **Operation at high beam load in pulse mode & Time of flight detectors**

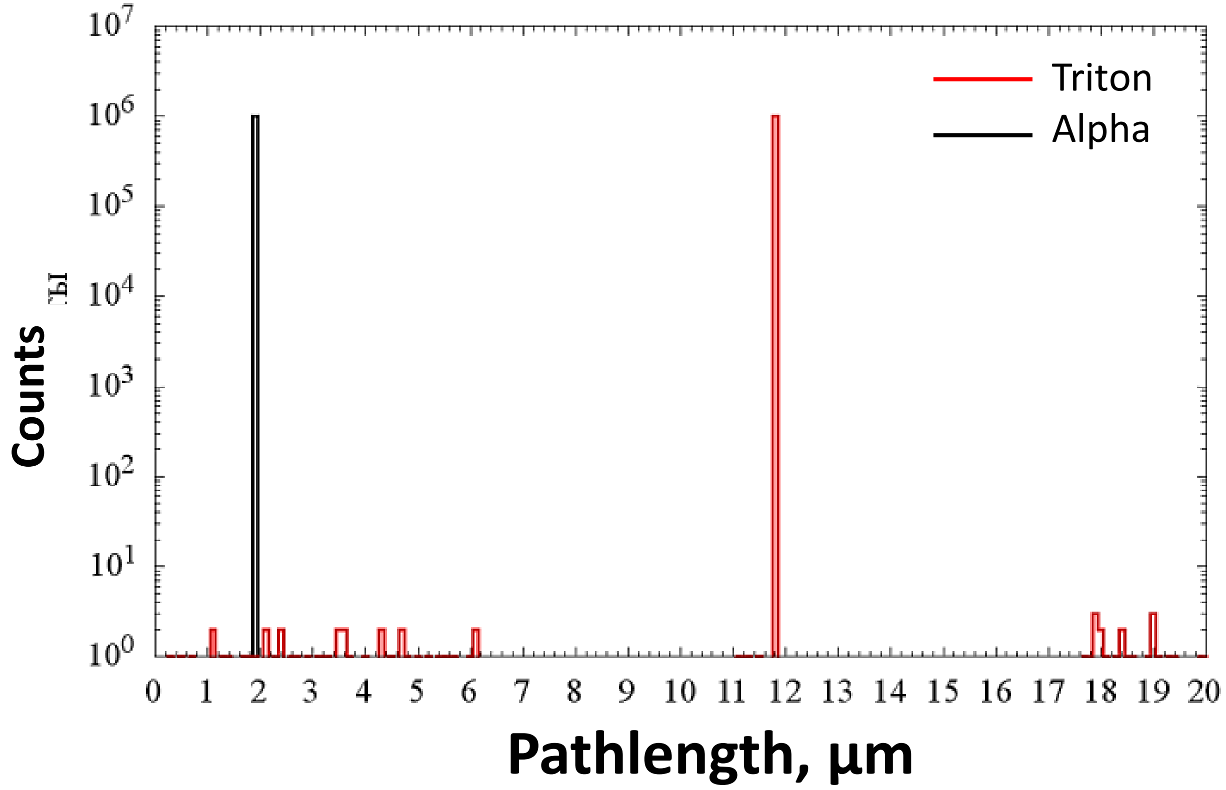
Tb-doped — **High light yield** ⇒ **Low exposure time**

Gd-containing — **Effective neutrons absorption** ⇒ **Thin scintillator layer with small particle size to improve spatial resolution**

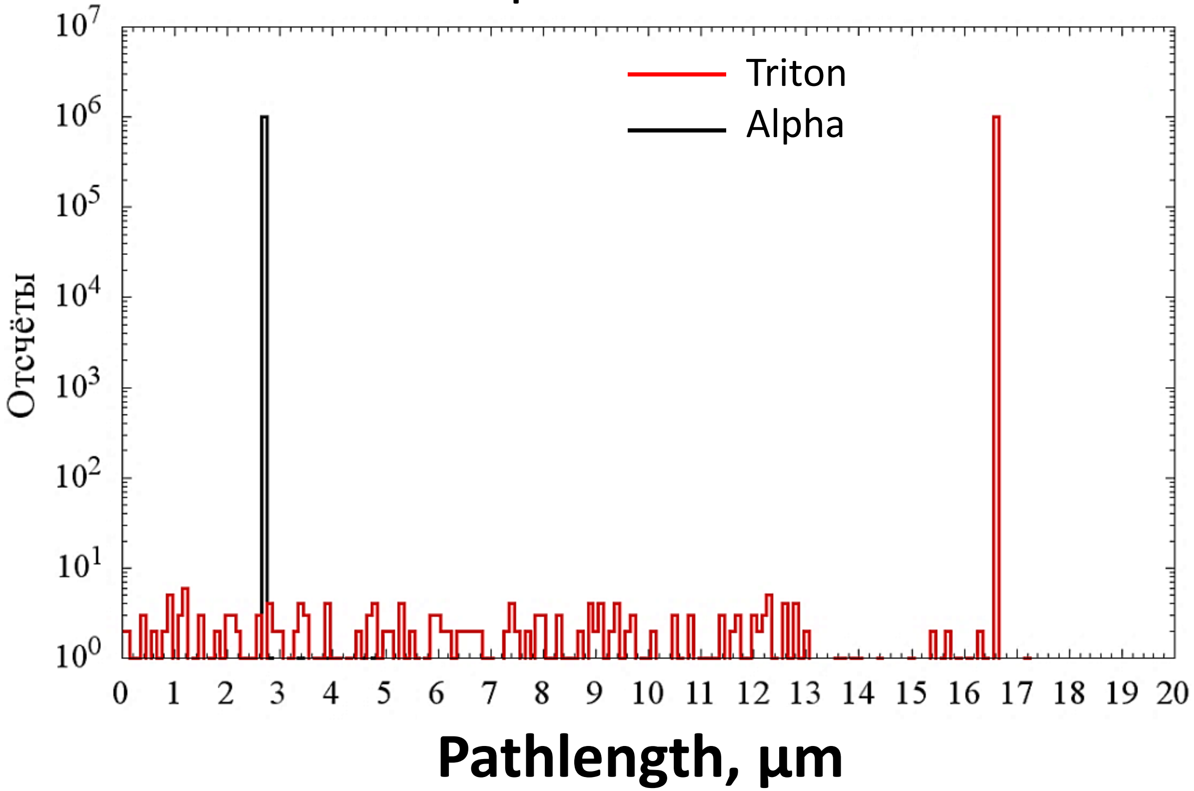
Scintillator and neutron absorber particle sizes calculation

The modeling was performed in GEANT4 (CERN) software

Model target: 500 µm GYAGG sphere
Number of particles emitted: 10^6



Model target: ^{6}LiF layer
Number of particles emitted: 10^6



Main registration channel - $^3H^+$

Particle size requirements: LiF < 2-3 µm, GYAGG > 20 µm

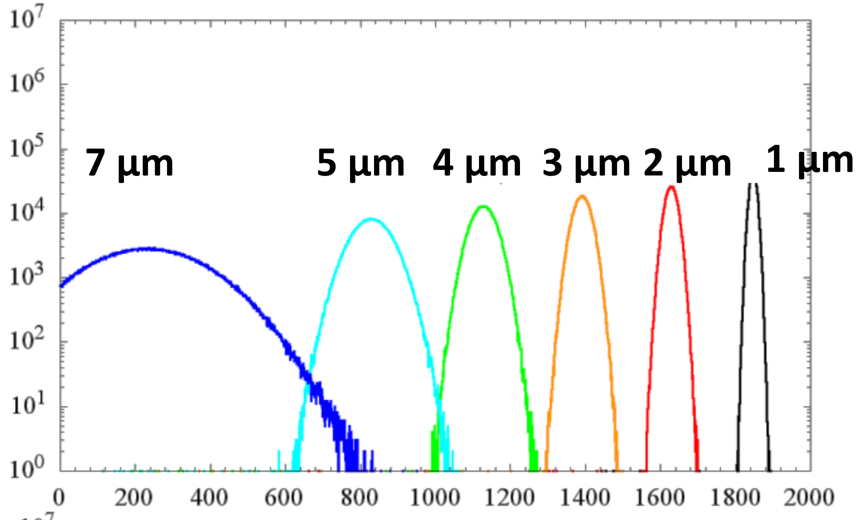
Energy loss in binder & absorber calculation

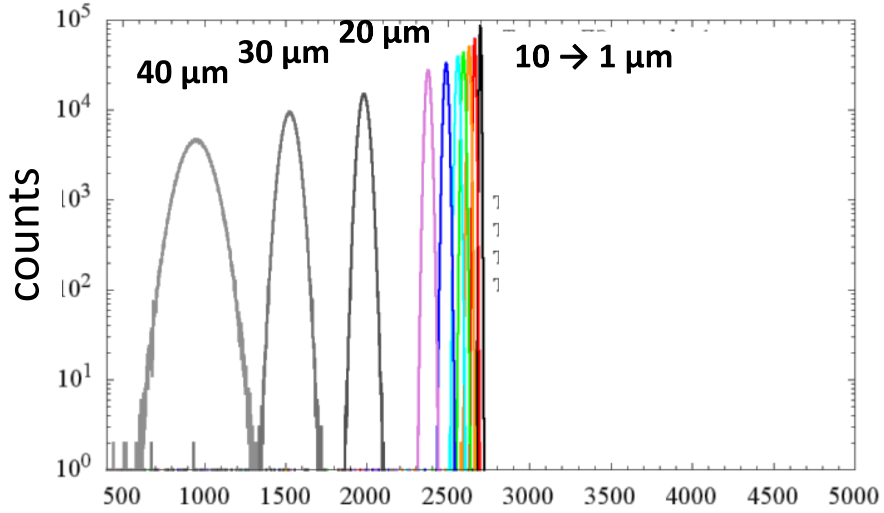
The modeling was performed in GEANT4 (CERN) software

2.05 MeV Alpha particles

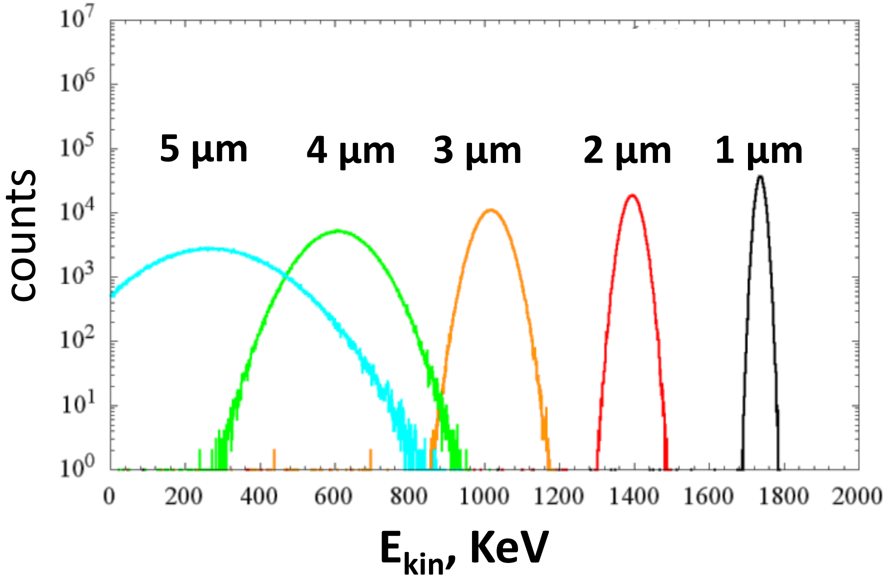
2.73 MeV Tritons

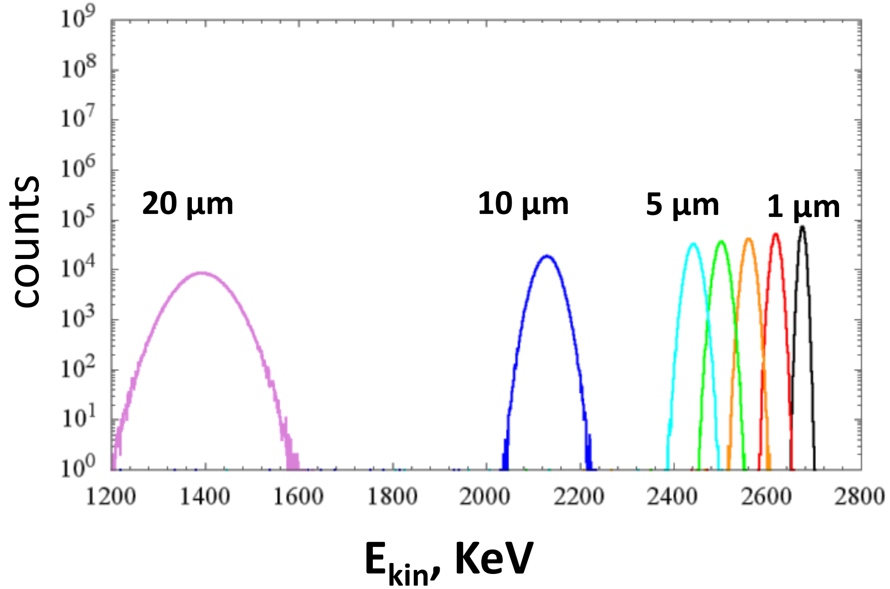
Binder: epoxy resin Huntsman TDR1100





Absorber: ^{6}LiF

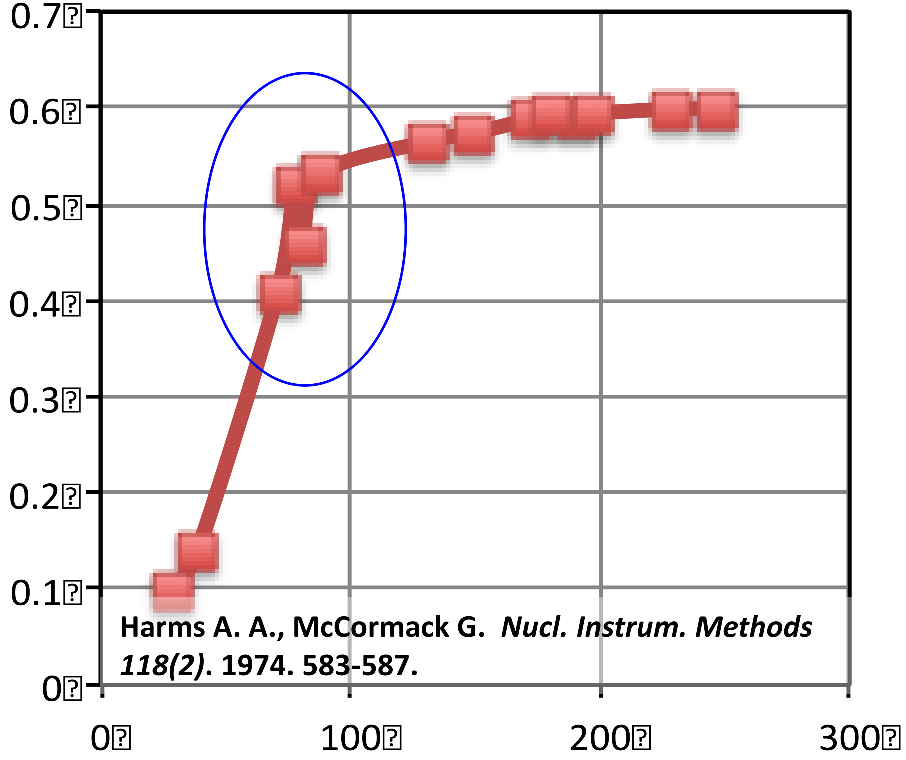




Direct Gd signal registration

$$^{n}\mathrm{Gd} + n \rightarrow {}^{n+1}\mathrm{Gd} + \gamma + e^{-}$$

The yield of conversion electrons with energies less than or equal to the given energy:



Conversion electrons energy, keV

Gd conversion electron pathlength;
n Gd ~ 6 µm, in Si ~ 25 µm

LY (GYAGG:Ce) = 30-50 photon/keV.
Screen filling by scintillator ~30 vol.%

Light output on absorption of
10-25 keV will be 300-1000 photons

Possible to detect by sensitive SiPMs

Scintillating screens composition

Scintillation pigments:

$Gd_{1.2}Y_{1.8}Ga_{2.5}Al_{2.5}O_{12}$:Ce **(GYAGG:Ce)**	Single crystal (grinded)
	Ceramics (grinded)
$Gd_{1.2}Y_{1.8}Al_2Ga_3O_{12}$:Tb **(GYAGG:Tb)**	Single crystal (grinded)
	Ceramics (grinded)
$Gd_3Al_2Ga_3O_{12}$:Ce **(GAGG:Ce)**	Single crystal (grinded)

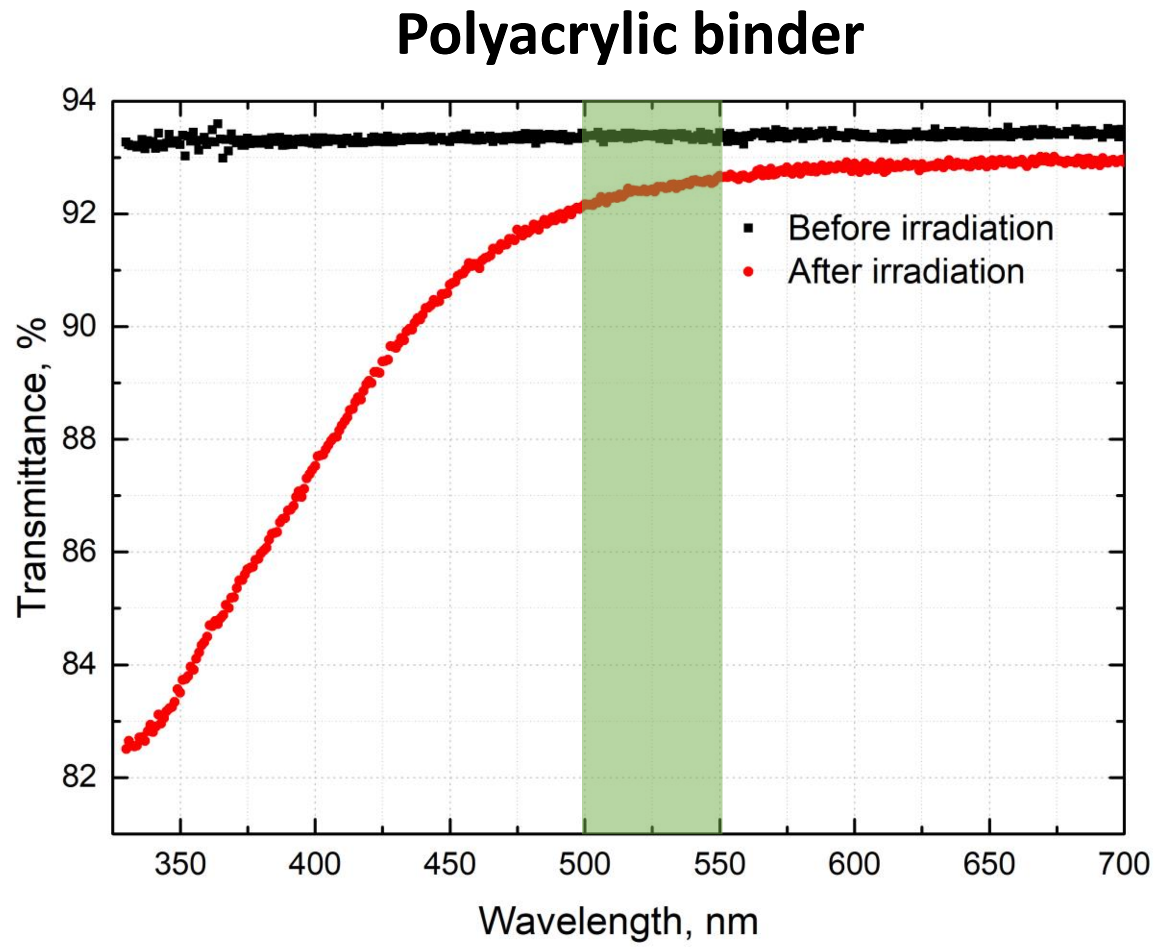
Binders:

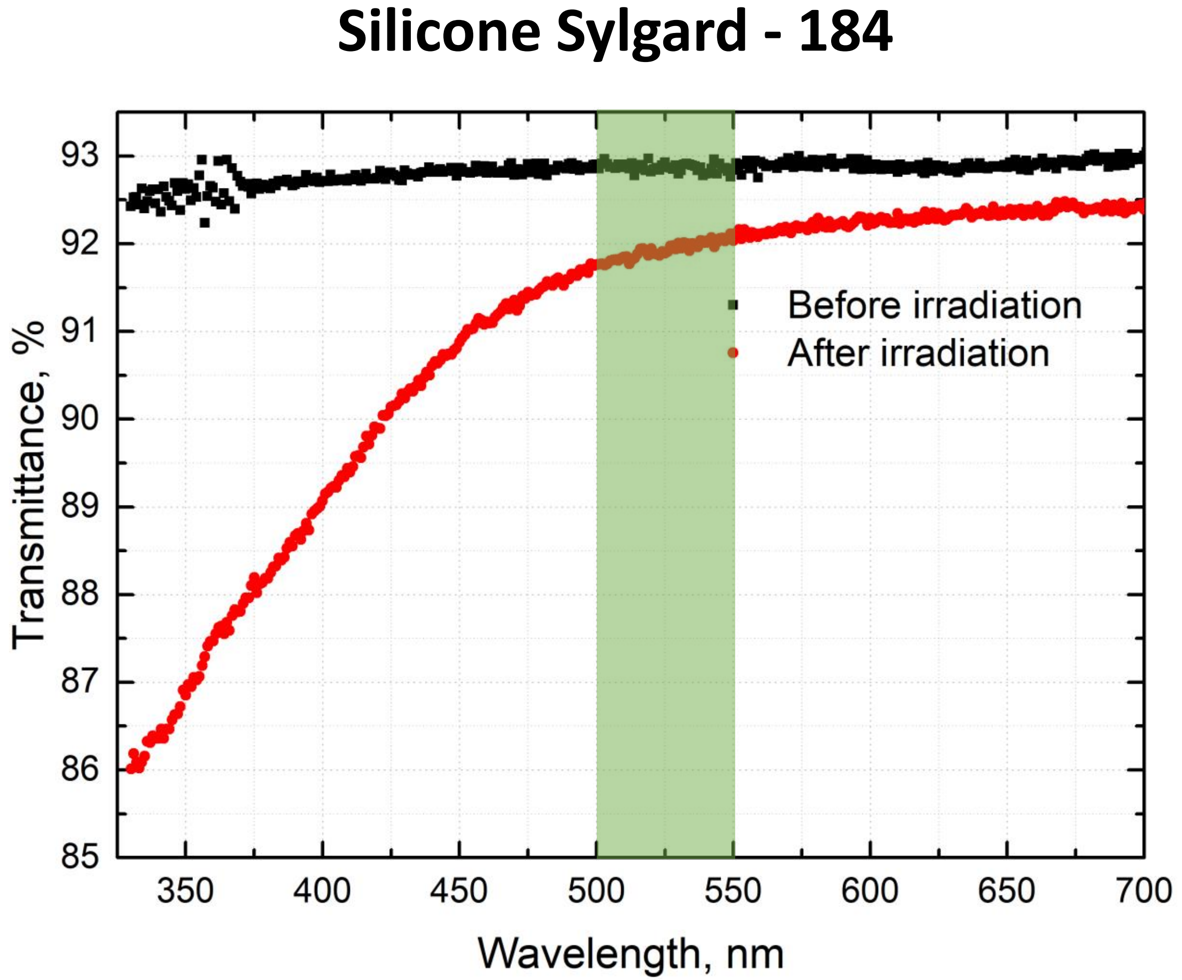
Polyacrylic water dispersion	Trade name CHP550
Silicone elastomer	Trade name Sylgard - 184
Polysilicate binder	

Neutron absorber:

^{6}LiF

Radiation stability of binders



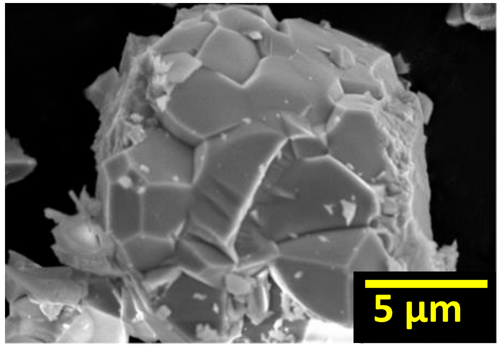


Transmittance loss ~3% at emission λ_{max} of scintillators

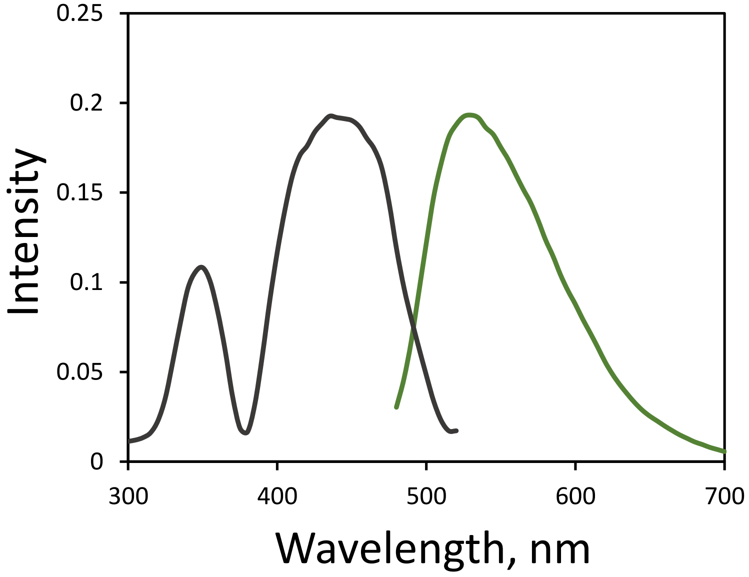
Pigments characterization

$Gd_{1.2}Y_{1.8}Al_2Ga_3O_{12}$:Ce

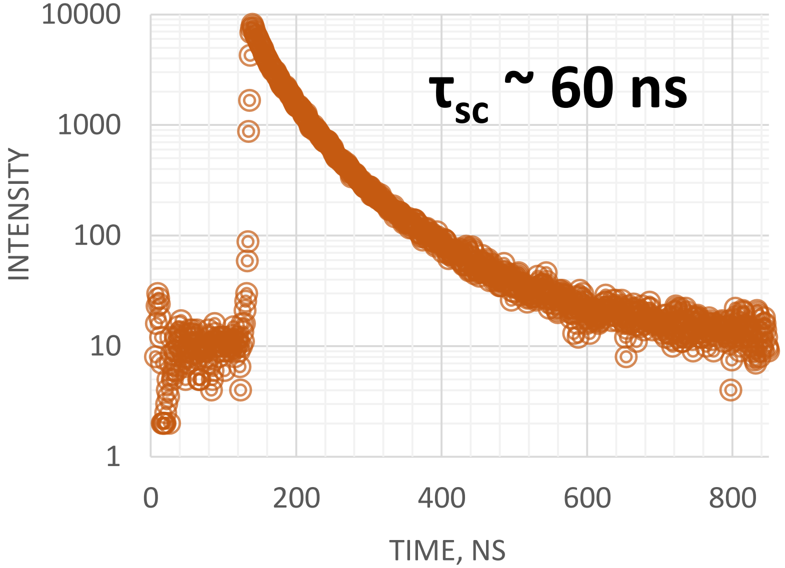
LY – up to 60 000 ph/MeV



Photoluminescence spectra

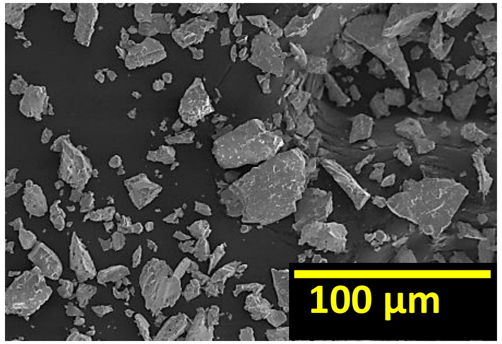


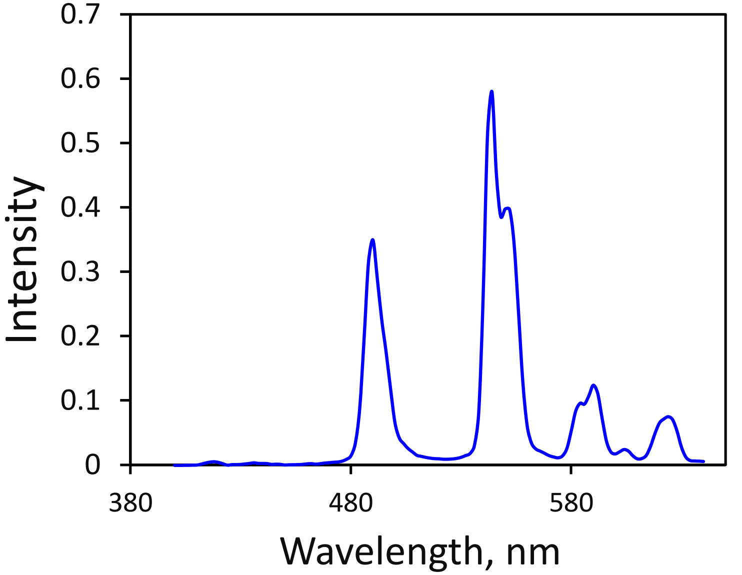
Scintillation kinetics

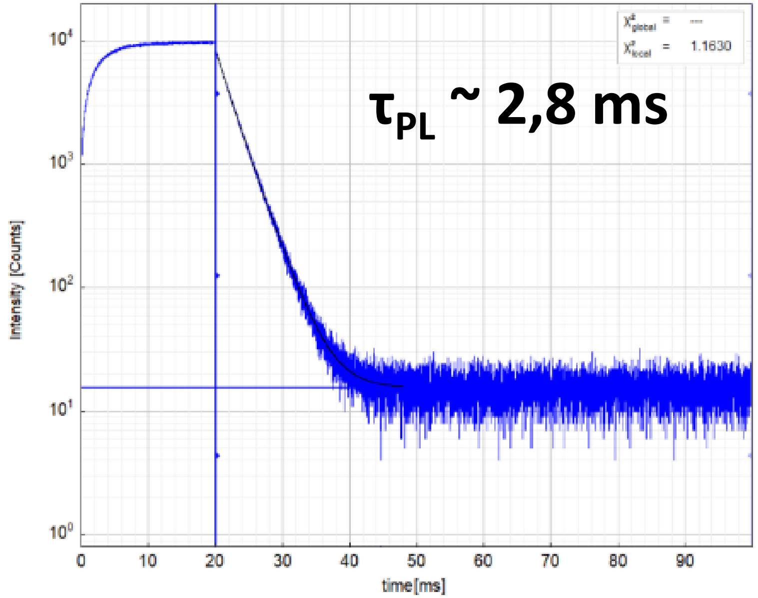


$Gd_{1.2}Y_{1.8}Al_2Ga_3O_{12}$:Tb

LY – up to 200 000 ph/MeV





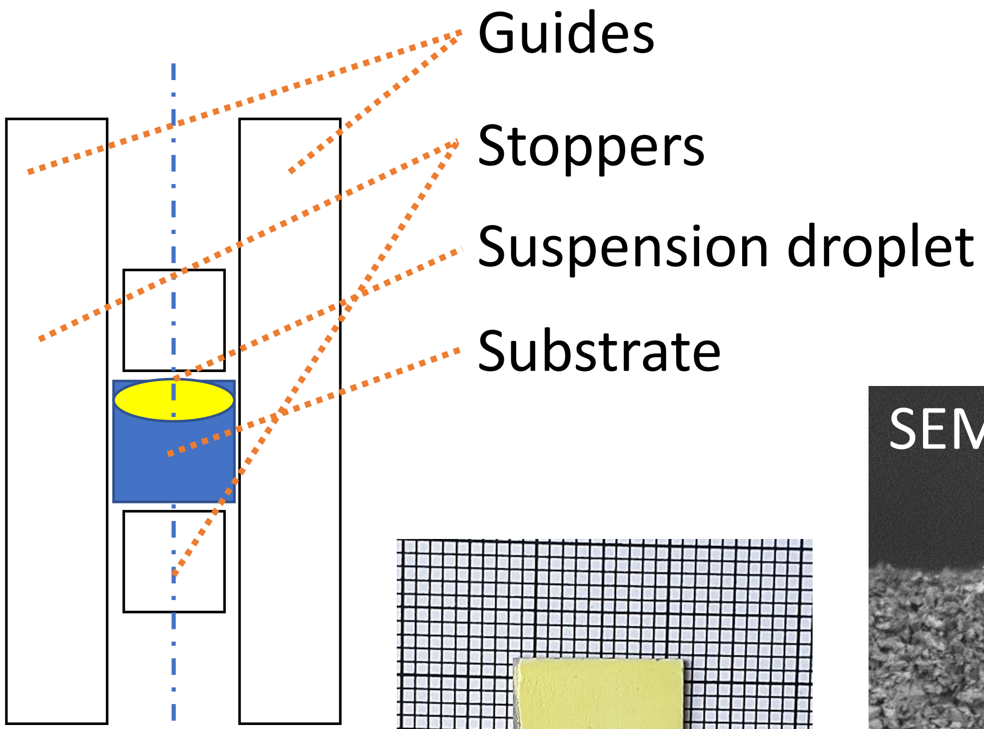


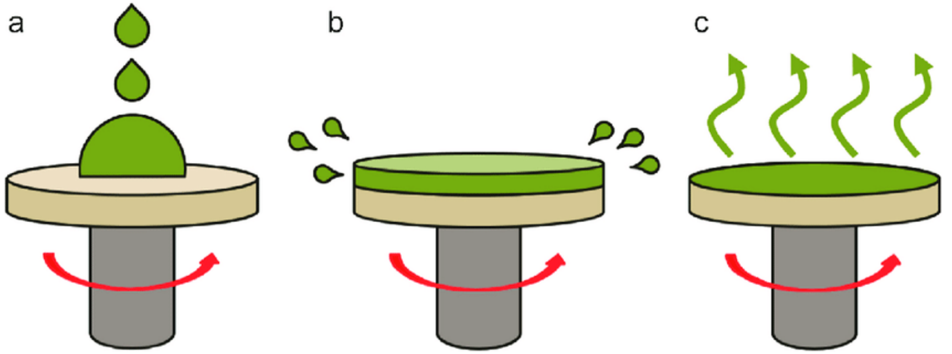
Preparation of screens samples

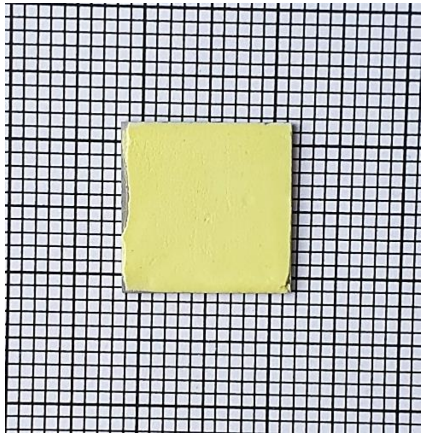
Coating method - Master Blade

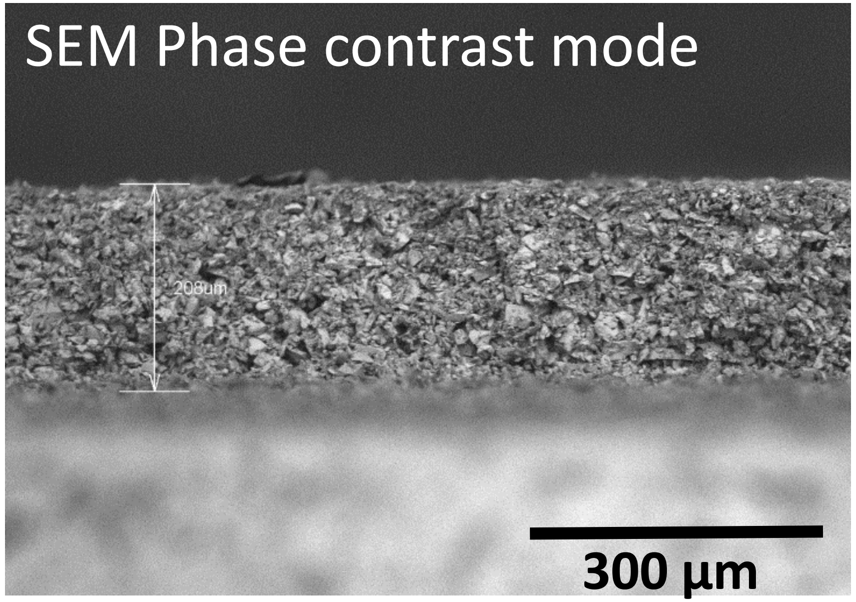
Coating method - Spin Coating

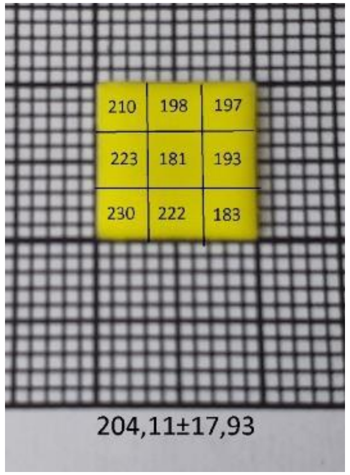
Layer thickness = (50 - 200 µm)

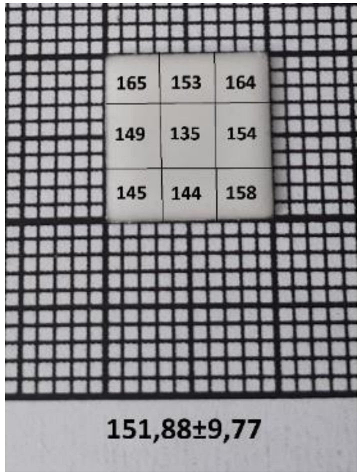












Pulse height spectra acquired at 5.5 MeV α-particles irradiation

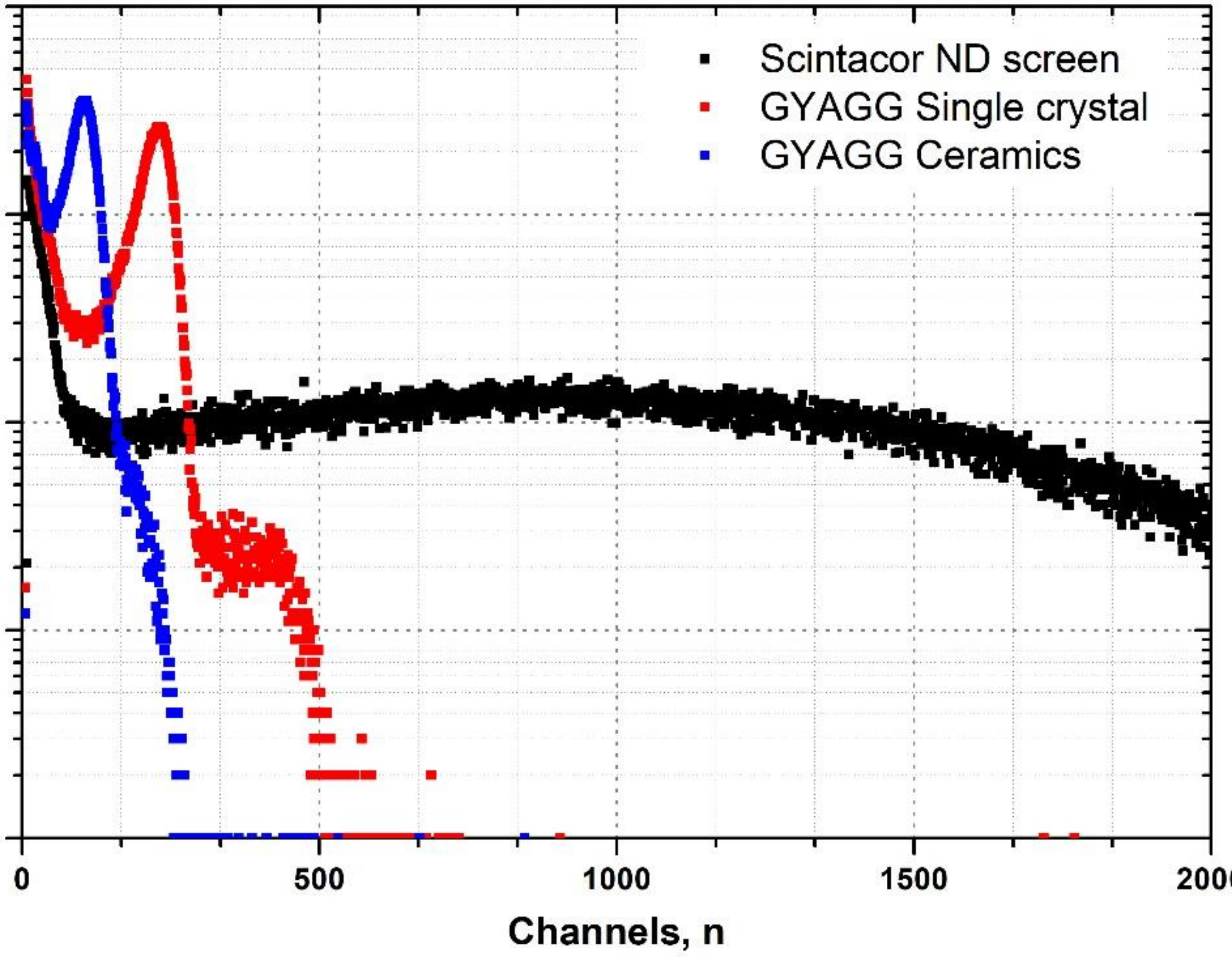
12x12x0,2 mm samples

Layer filling ~90% by volume

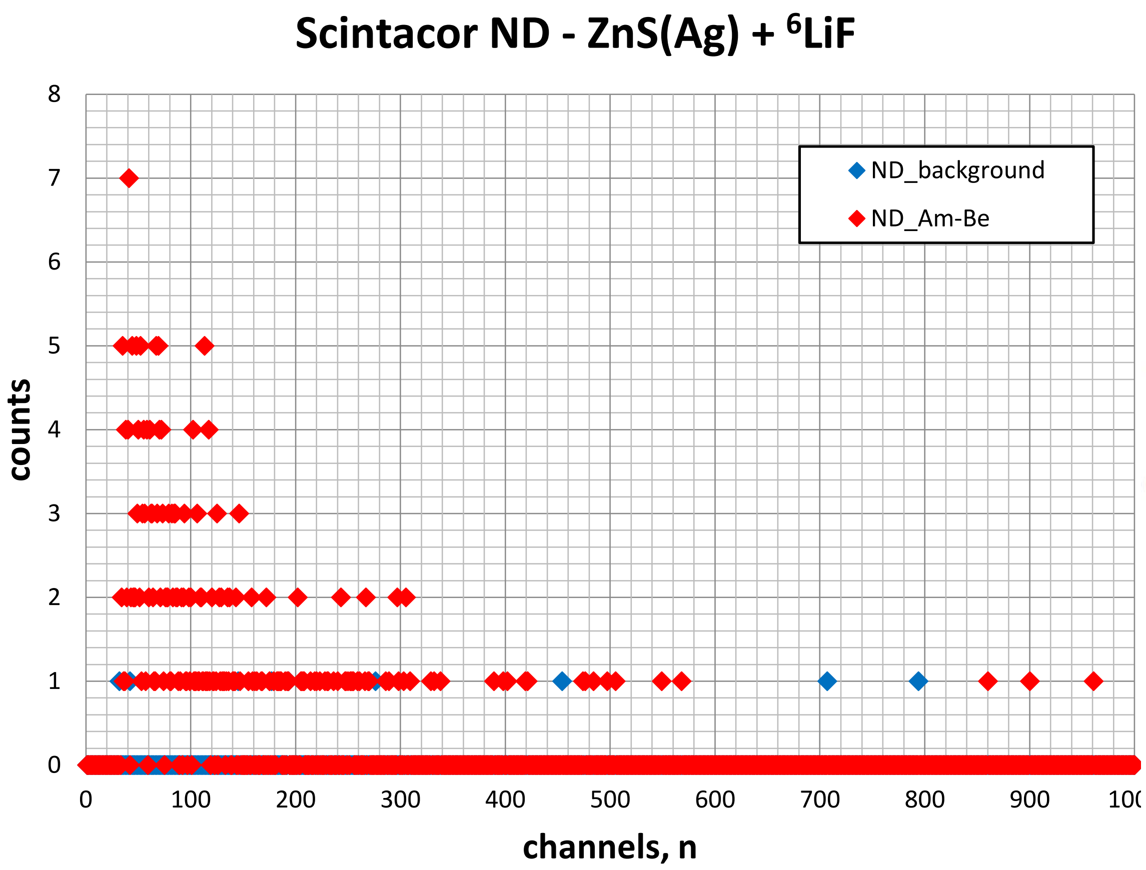
Phosphor load ~50 mg/cm²

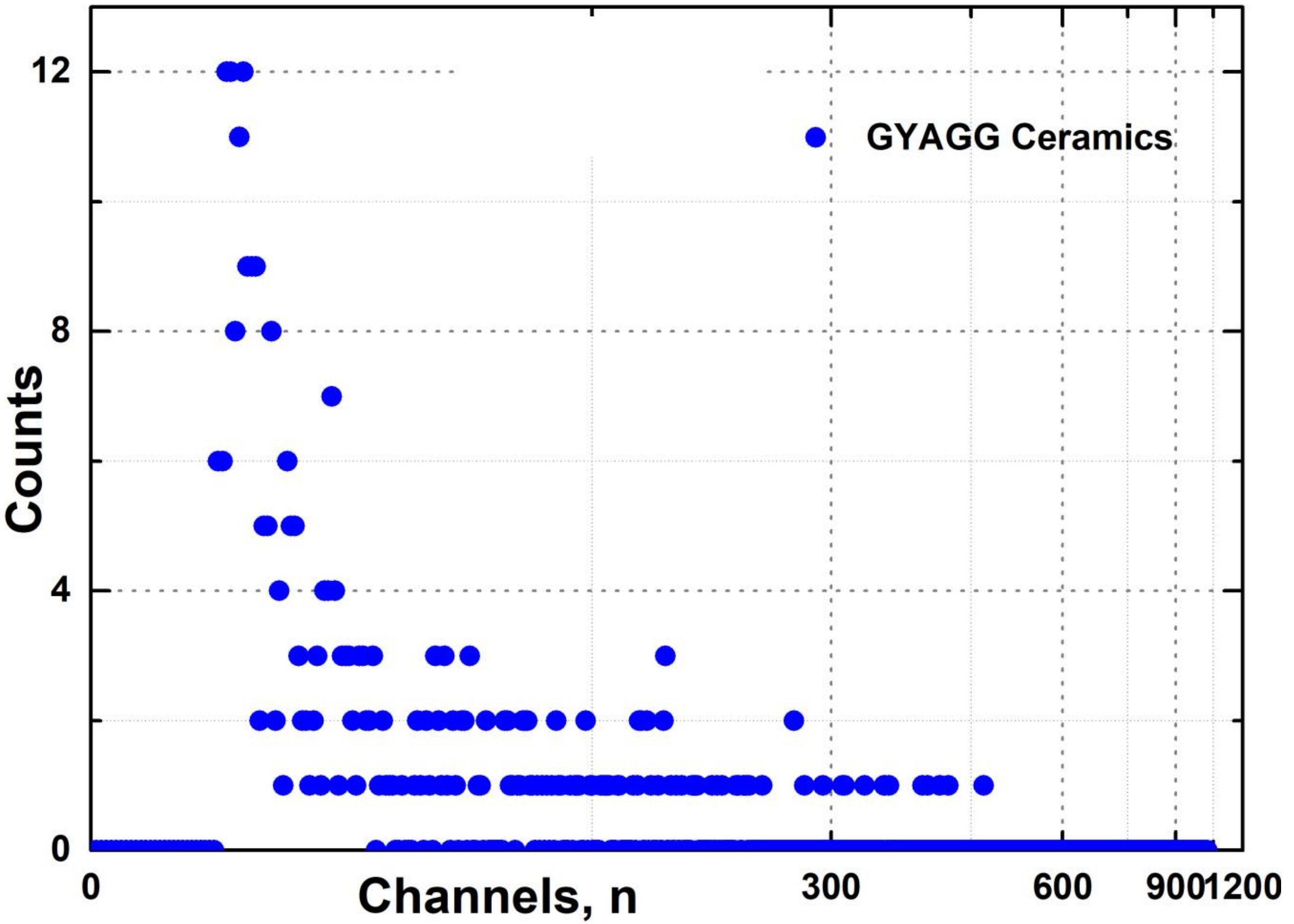
ND screen peak position	900
GYAGG single crystal peak position	229
GYAGG ceramics peak position	111
Light yield of ZnS:Ag (under α-particles)	49 400
Light output of GYAGG single crystal	12 500

Source ^{241}Am
Reflection mode



Response to neutrons from the Am-Be source of samples





The integral over the neutron spectrum from 25 - 1000 channels (2σ = ±35)

Scintacor ND screen	**299**
GYGAG_Cer 10/30/60 screen	**321**

And 100 times faster!

Evaluation of Light output & Spatial resolution

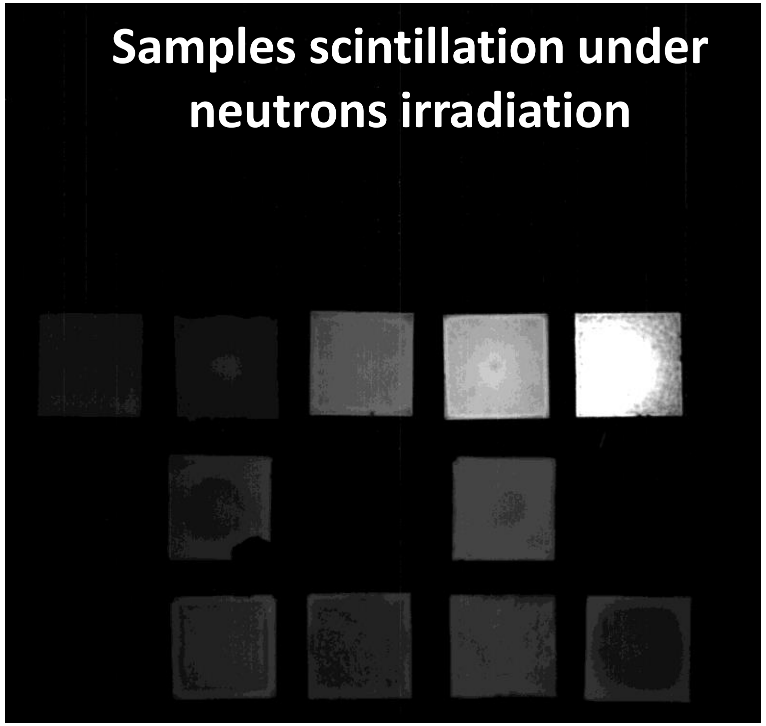
Performed in Kurchatov synchrotron-neutron research complex, Moscow, Russia

IR - 8 neutron reactor. Neutron tomography station

FOV = 75x75 mm
n flux = $3.6 \cdot 10^6$ n/cm^2 (λ = 2.4 Å)
SR_{min} = 200 µm

γ + n polychromatic beam with a thermal neutron spectrum of 1.7 - 4.5 Å (4 - 28 meV).
Reference: LiF / ZnS 100 µm

n - monochromatic beam with a wavelength of 2.4 Å (14 meV)
Reference: LiF / ZnS 200 µm



Light output & Spatial resolution

Composition = Scintillator/Absorber/Binder, % Vol

Scintillator	Thickness, µm	Composition	Light output rel. to LiF/ZnS
$Gd_{1.2}Y_{1.65}Al_2Ga_3O_{12}:Tb_{0.15}$	200	28/29/43	3 times worse under γ+n
			8 times worse under n
	130	23/73/4	2 times worse under γ+n
			6 times worse under n
$Gd_{1.2}Y_{1.785}Al_2Ga_{2.97}O_{12}:Ce_{0.015}$	60	23/73/4	8 times worse under γ+n

Scintillator	Thickness, µm	Composition	SR, µm	Scint. Kinetics, sec
$Gd_{1.2}Y_{1.65}Al_2Ga_3O_{12}:Tb_{0.15}$	60	23/73/4	212	$2 \cdot 10^{-3}$
$Gd_{1.2}Y_{1.785}Al_2Ga_{2.97}O_{12}:Ce_{0.015}$	130	23/73/4	216	$8 \cdot 10^{-8}$
Reference ^{6}LiF/ZnS	100 - 200	-	220	$4.5 \cdot 10^{-6}$
Reference $Gd_2O_2S:Tb$	50	-	202	$2 \cdot 10^{-3}$

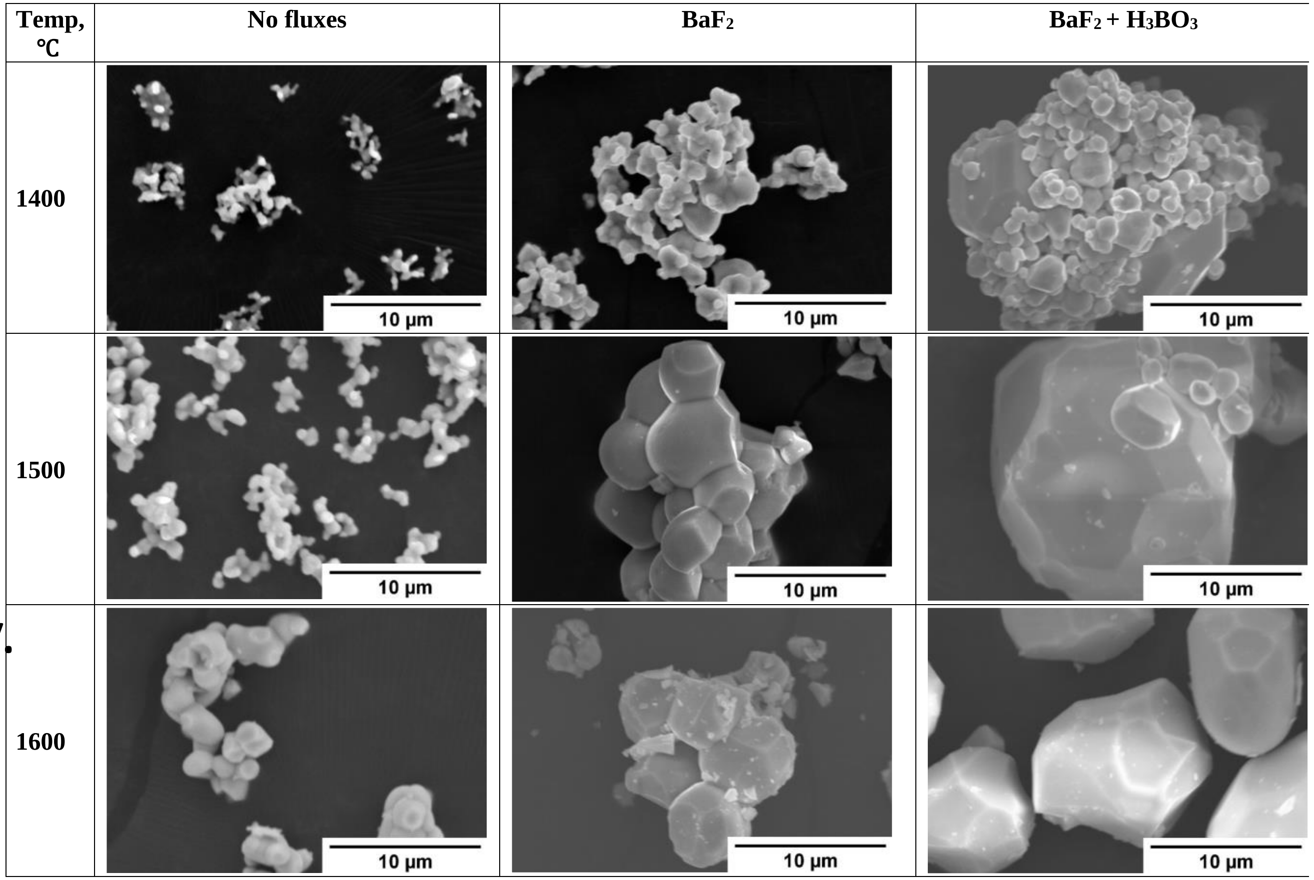
Conclusions

Our samples have shown the result (LO, SR) close to the commercial ones
(but still much work to do)

Some points for improvement:

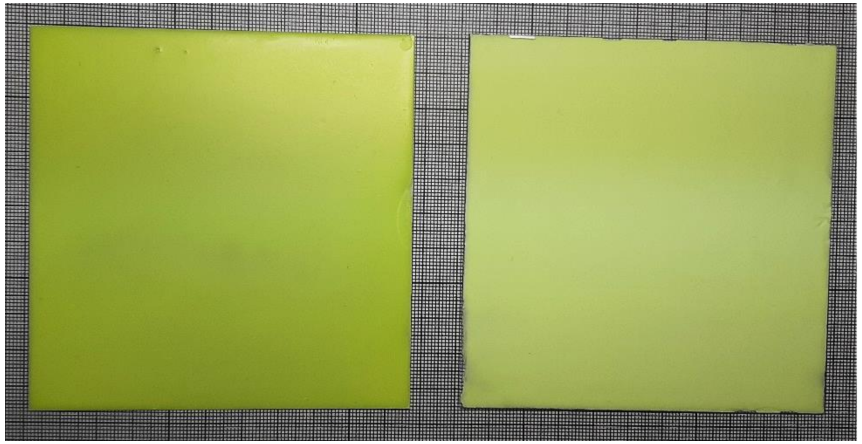
- Optimize the composition
- Light extraction from the scintillation pigment particles

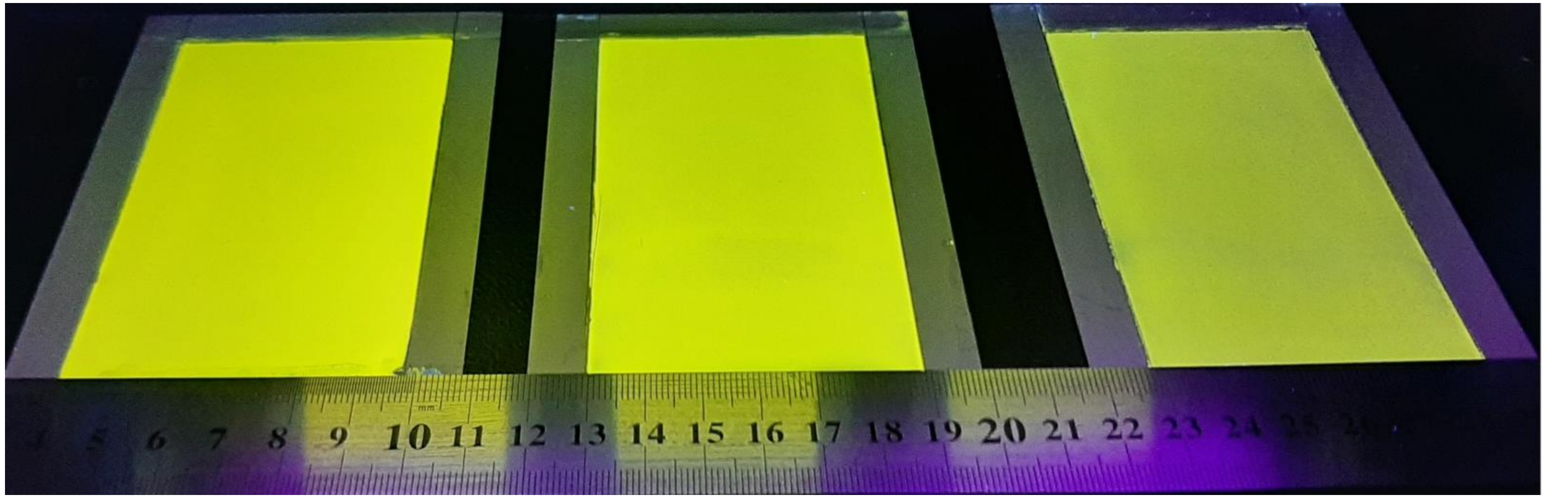
- Use fluxes to obtain rounded particles. Easier, but uncertain effect on scintillation
- Increase ceramic density and transparency. Harder, but will work



Thank You for the attention

Designing of larger screens is possible





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