Response of different types of Gd based scintillation materials to Am-Be neutron source

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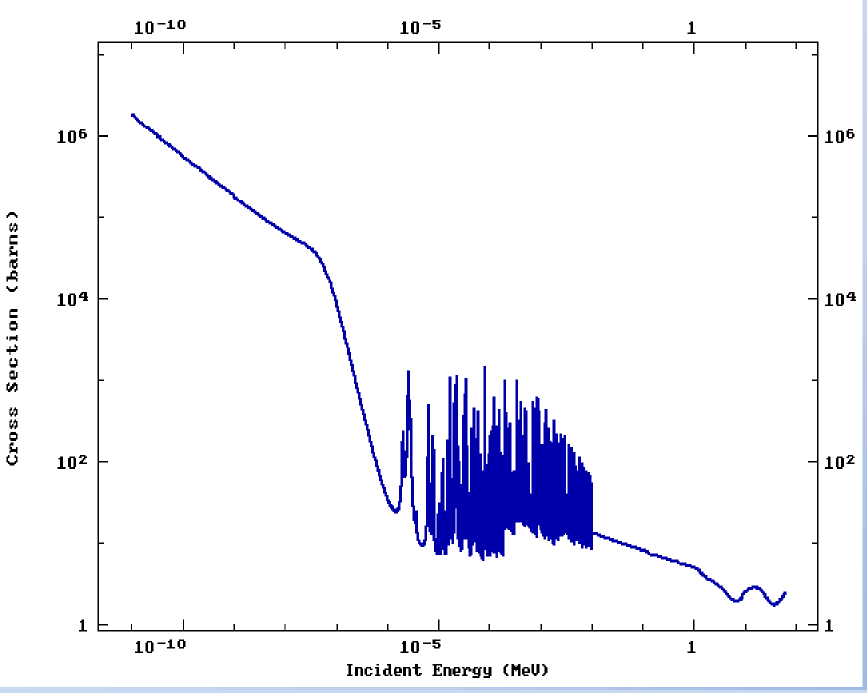
Intelum

CRYSTAL CLEAR

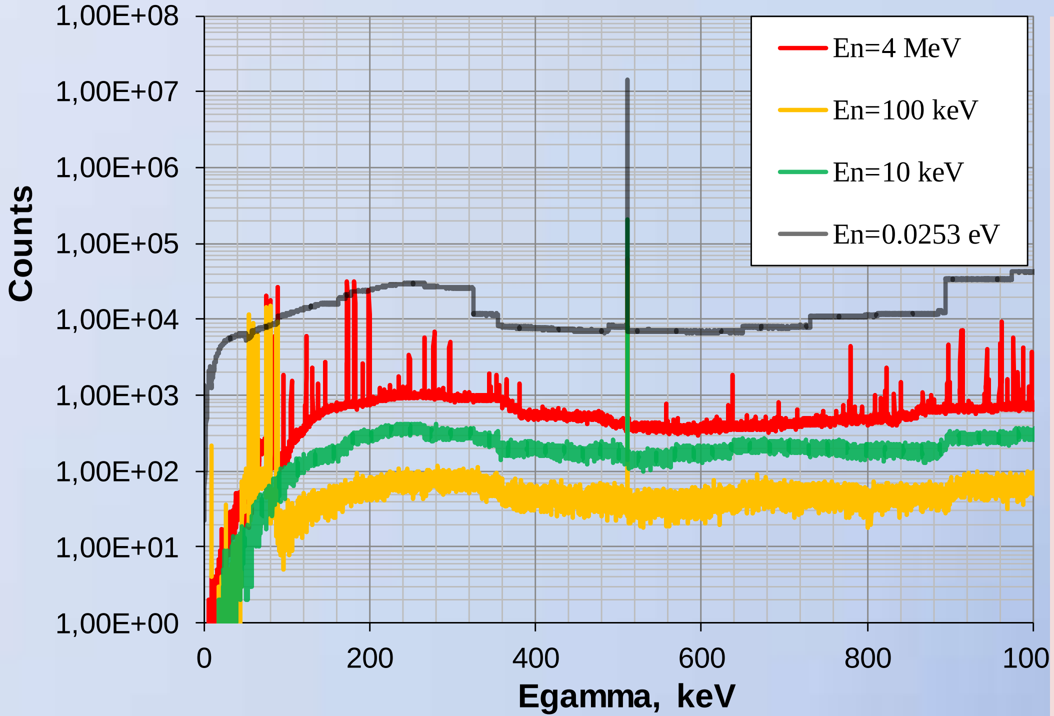
Gd isotopes natural mixture is sensitive to neutrons



Neutron total cross sections of natural mixture of Gd isotopes
Nuclear Data File (ENDF), https://www-nds.iaea.org/exfor/endf.htm

- **Characteristic for them broad zone of resonances increases the neutron absorption efficiency for neutron energies from 1.0 eV up to 10 keV;**
- **Starting from ~ 55 keV threshold of the neutron energy, the process of the neutron inelastic scattering is accompanied by the gamma-quanta emission, forming multiple soft lines in the resulting gamma-quanta spectrum**

Production of γ-quanta in Gd(n, γ)



- The 511 keV gamma-line presents across all gamma spectra;
- There are no prominent soft γ-lines in the spectra for thermal neutrons (E_n = 0.0253 eV) and for neutrons with E_n = 10 keV;
- The γ-lines with energies <100 keV
- arise in spectrum for E_n = 100 keV
- resulting from inelastic neutron
- scattering having a threshold
- ~E_n = 55 keV.
- Numerous gamma-lines present
- across all the gamma-spectrum
- for E_n = 4 MeV.

Spectra of the individual energies of the emitted gamma quanta in metallic gadolinium with 2 mm thickness, irradiated with monochromatic neutrons, simulated with GEANT4

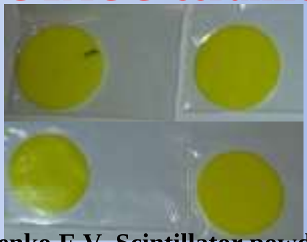
Gadolinium contained materials chosen for tests

GAGG is a neutron-sensitive scintillation detector. This recently developed material combines high stopping power, high light yield and fast scintillation kinetics – an attractive match for γ-radiation spectrometry, which is necessary for neutron detection with Gd-based materials.
Ceramics GYAGG $(Gd,Y)_3(Ga,Al)_5O_{12}$:Ce and Glass ceramics DSB ($BaO*2SiO_2$: Ce) heavy loaded with Gd can be considered as cheap alternative solutions for cases of the large volume detector systems. GYAGG ceramics is translucent material, DSB materials contains relatively high concentration of macrodefects due to not optimal growing technology. It limits the light collection of the materials.

Material	Emission maximum, nm	Light yield, ph/MeV	Gd content, at./cm^3
Monocrystalline GAGG ($Gd_3Al_2Ga_3O_{12}$:Ce)	520	38000(RT) 46000(-45°C)	$1.3*10^{22}$
Ceramics GYAGG $(Gd,Y)_3(Ga,Al)_5O_{12}$:Ce	520	12000	$0.6*10^{22}$
Glass ceramics DSB ($BaO*2SiO_2$: Ce) heavy loaded with Gd	440/460	2000	$0.3*10^{22}$

GAGG monocrystalline

GYAGG ceramics



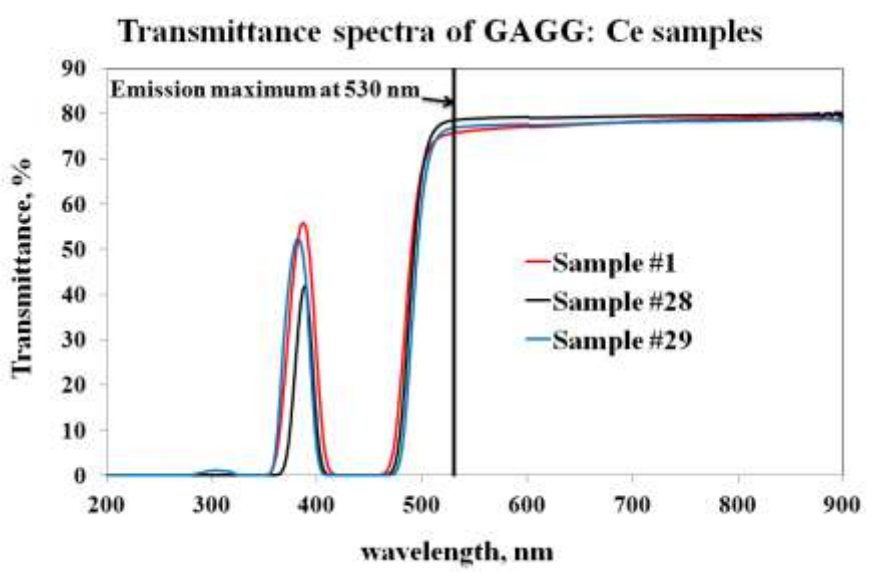
Gordienko E.V. Scintillator powders and ceramics of multicomponent oxides…

DSB loaded with Gd

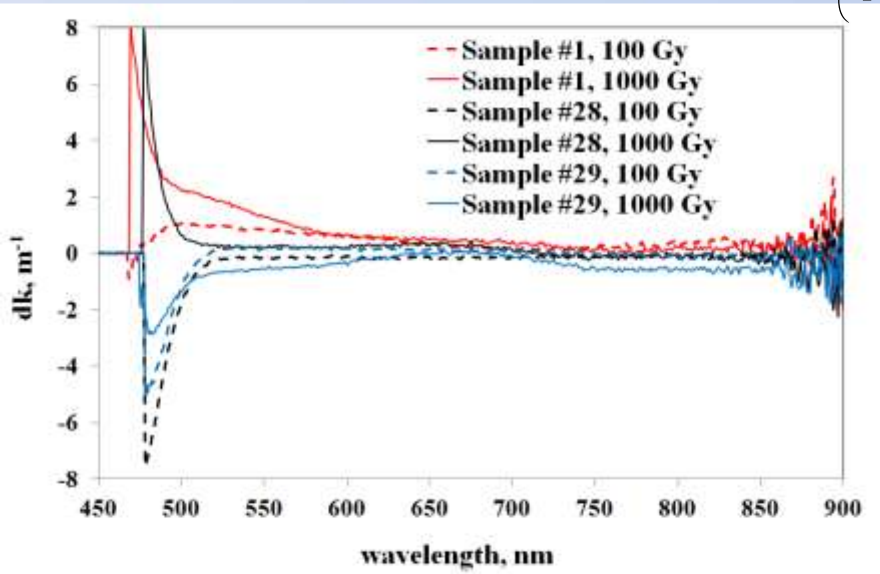
GAGG monocrystaline
Induced absorption after irradiation with gamma-quanta (^{60}Co)

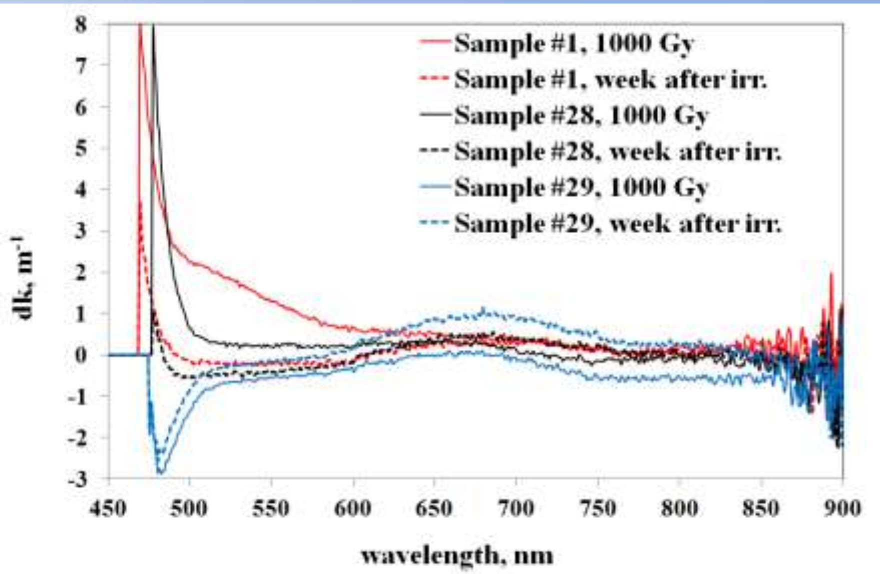
3 samples of GAGG were tested.
GAGG #1: Ce, Mg , Ti;
GAGG #28: Ce, Mg, Ti;
GAGG# 29: Ce

GAGG doped with Ce, Mg, Ti is perfect scintillation material designed to overcome drawbacks of Ce solely doped and Mg co-doped crystals.



$$\Delta k = \ln\left(\frac{T_{bef}}{T_{after}}\right)\cdot\frac{1}{d}$$

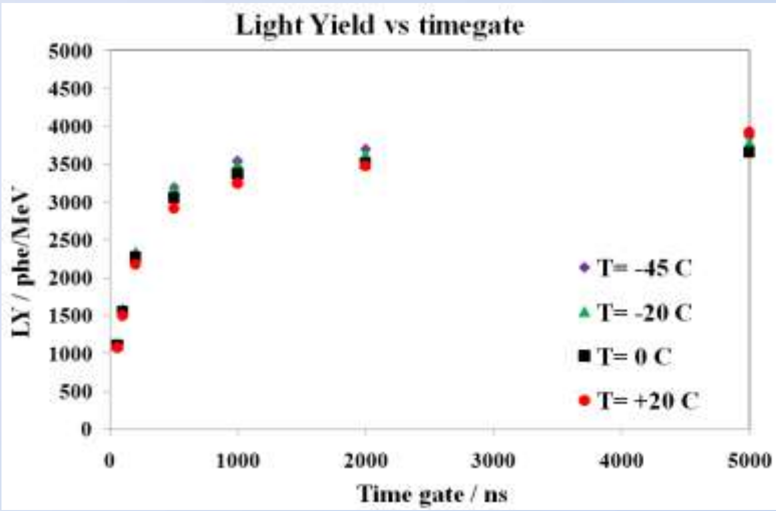


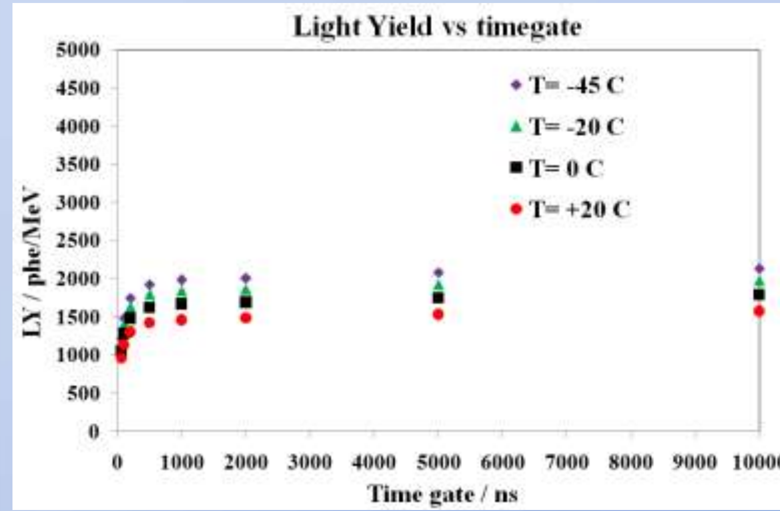


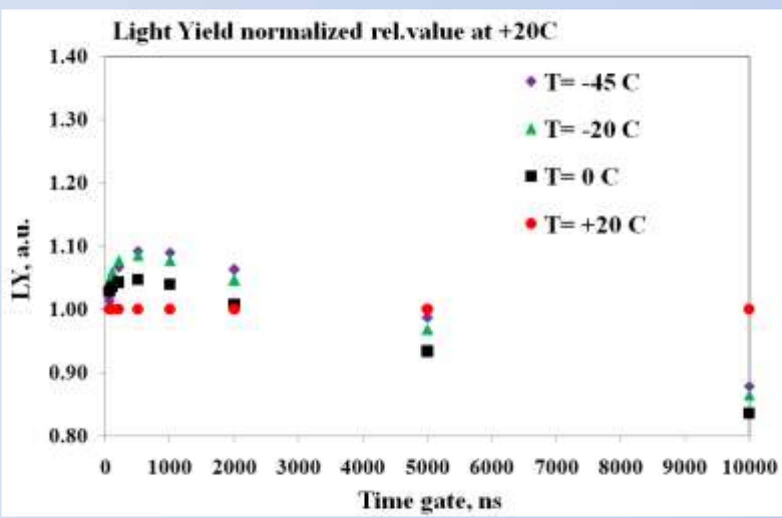
Lighy Yield of garnets vs operational temperature.

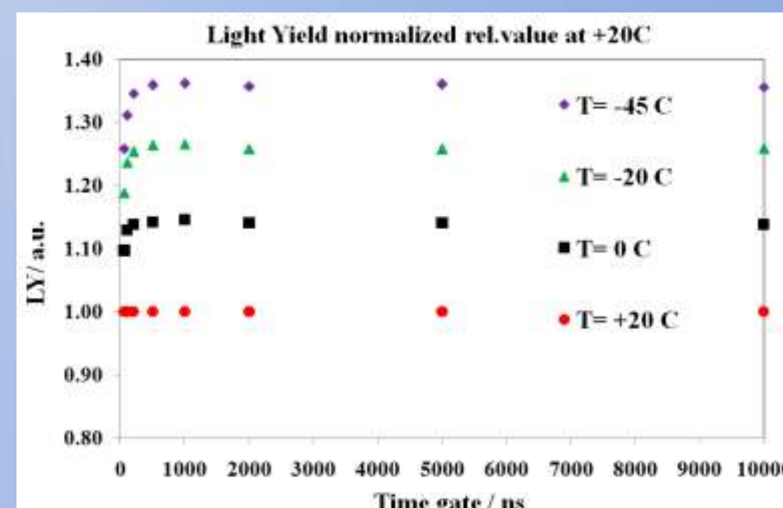
GAGG: Ce

GAGG: Ce + Mg, Ti





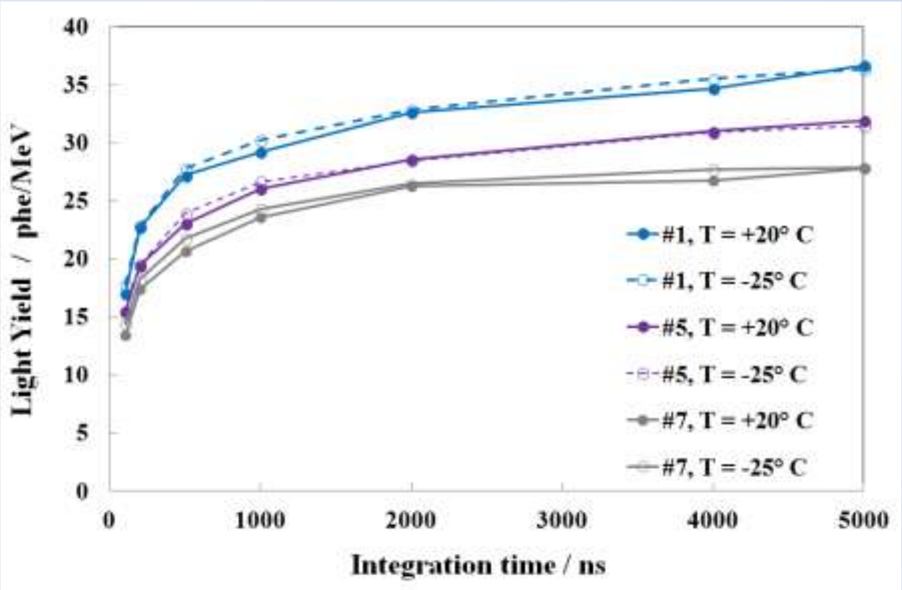




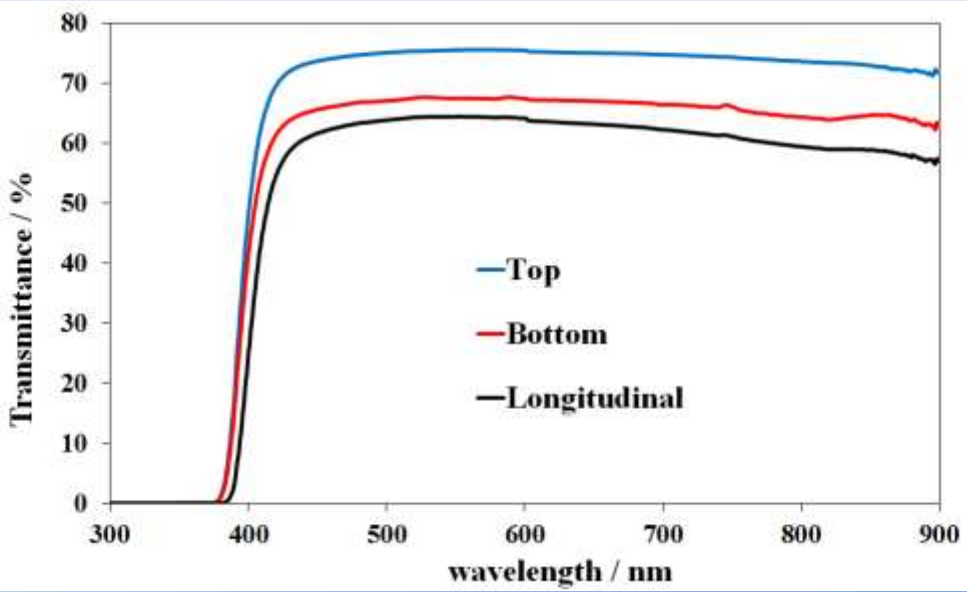
Light Yield vs integration time was measured (Hamamatsu PMT XP 2059, ^{241}Am)

Properties of the DSB material

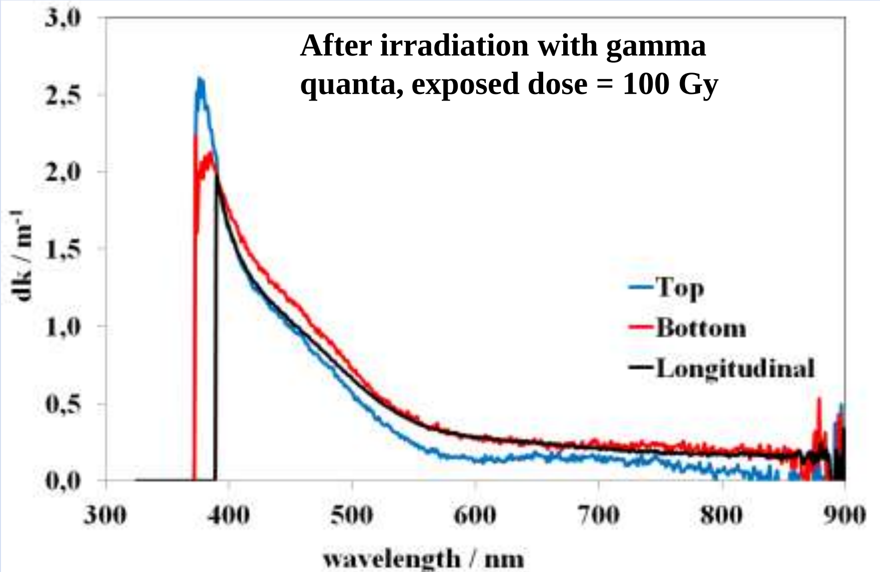
Light yield vs temperature

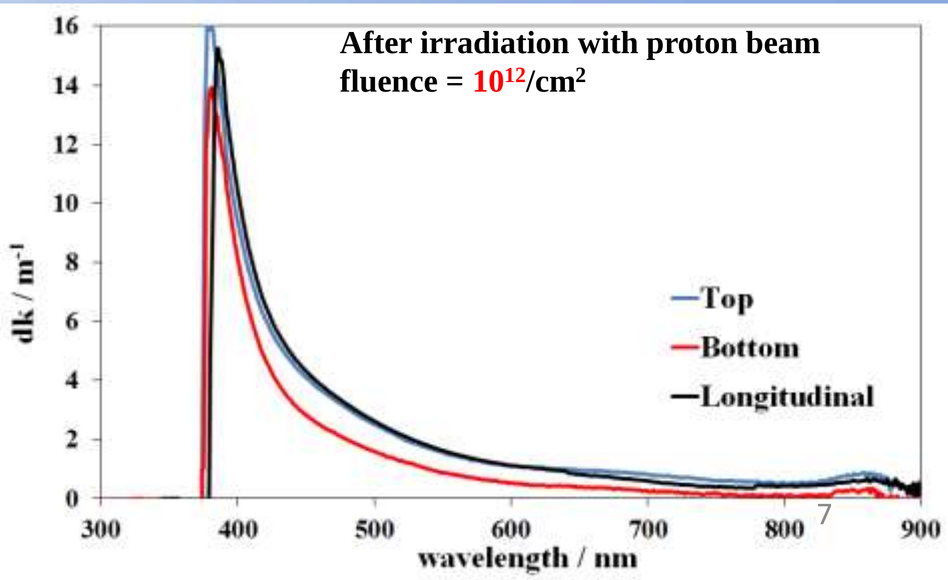


Optical Transmittance

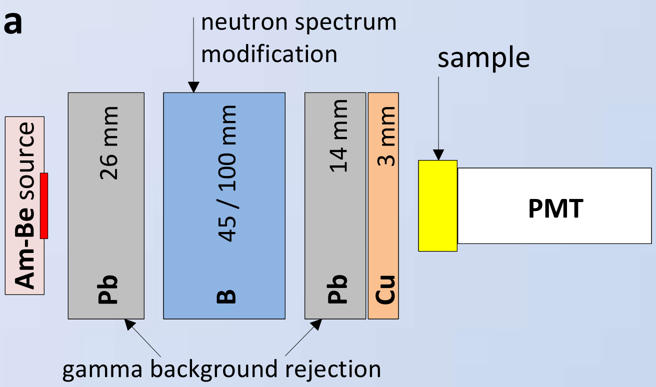


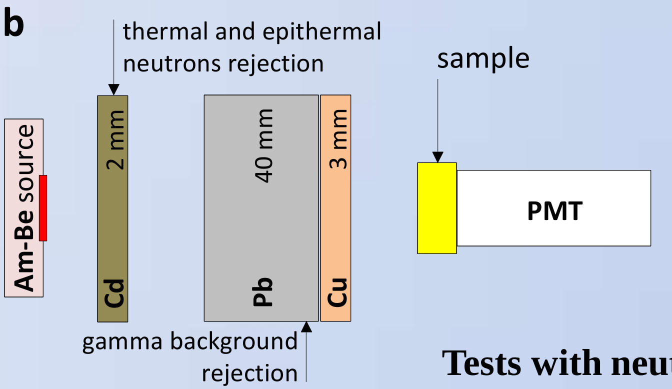
Radiation damage

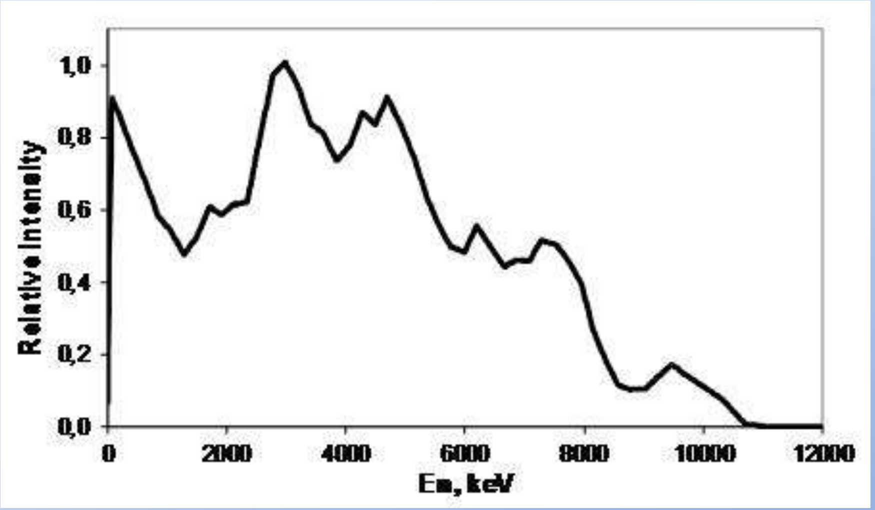




Layout of the measurement scheme





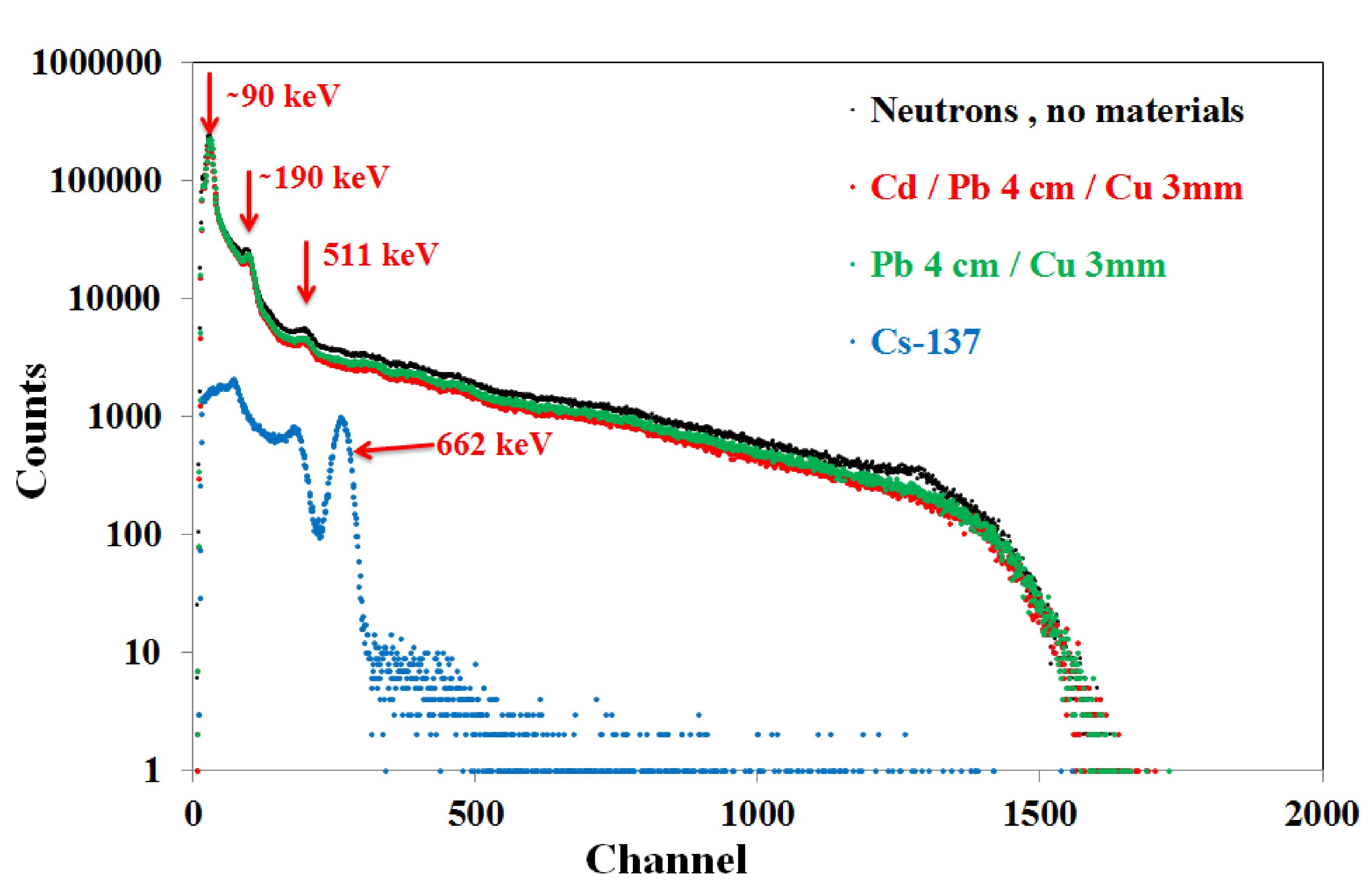


Spectrum of neutron energies from Am-Be neutron source, in accordance with ISO 8529-1:2001(E)

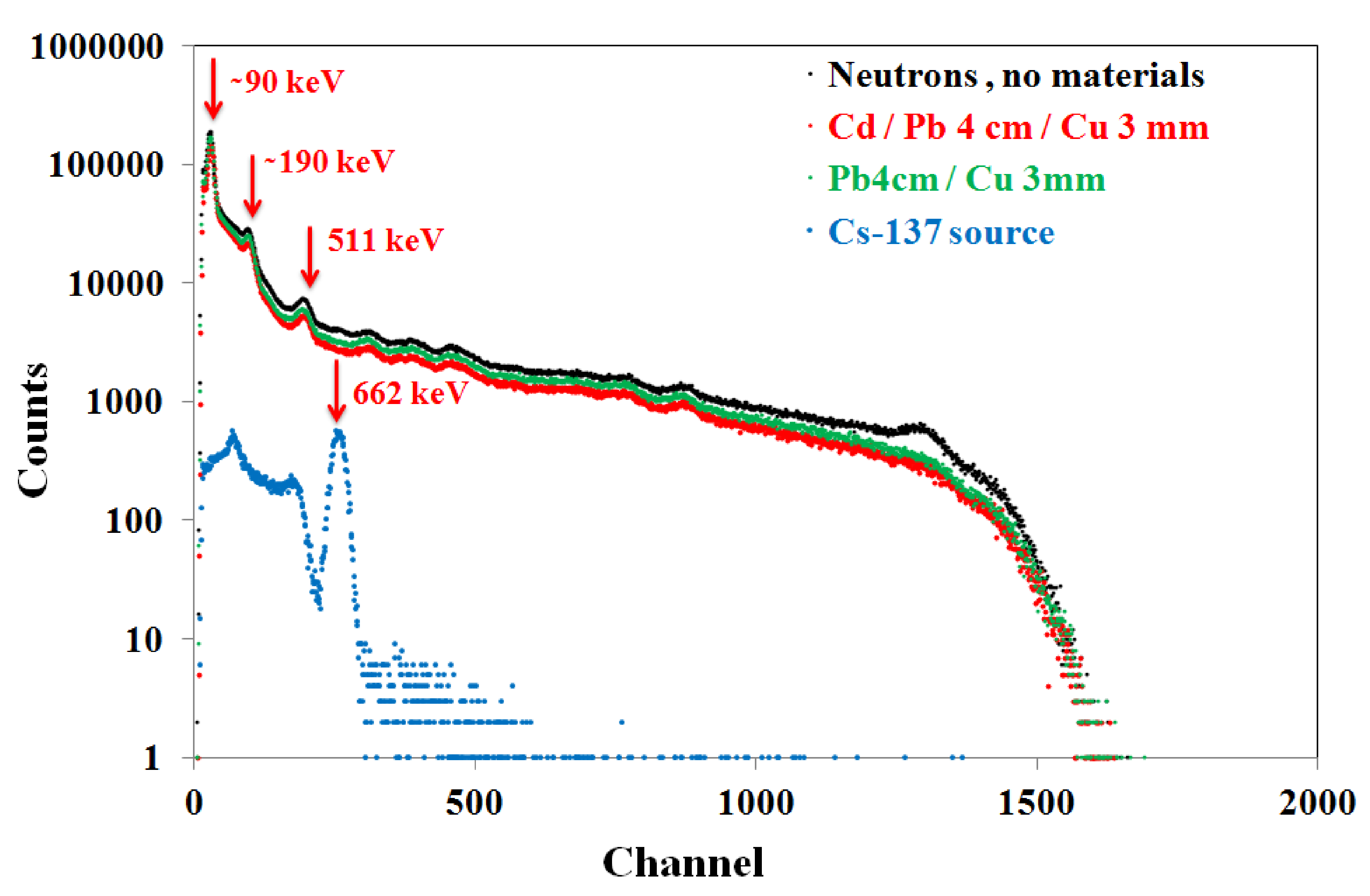
Kozlov D. Setup for characterization of scintillators to detect neutrons

Tests with neutrons of an Am-Be source (<En> = 4.2 MeV, En max = 11 MeV) have been performed. ^{241}Am source activity is 220 GBq,
with estimated neutron yield of ≥1.3 10^7 neutron/s.
Each sample was wrapped in multiple layers of Teflon® tape and attached to a Hamamatsu R2059 PMT.
The optical connection between samples and the PMT was performed with “Baysilone® M 300.000” optical grease.

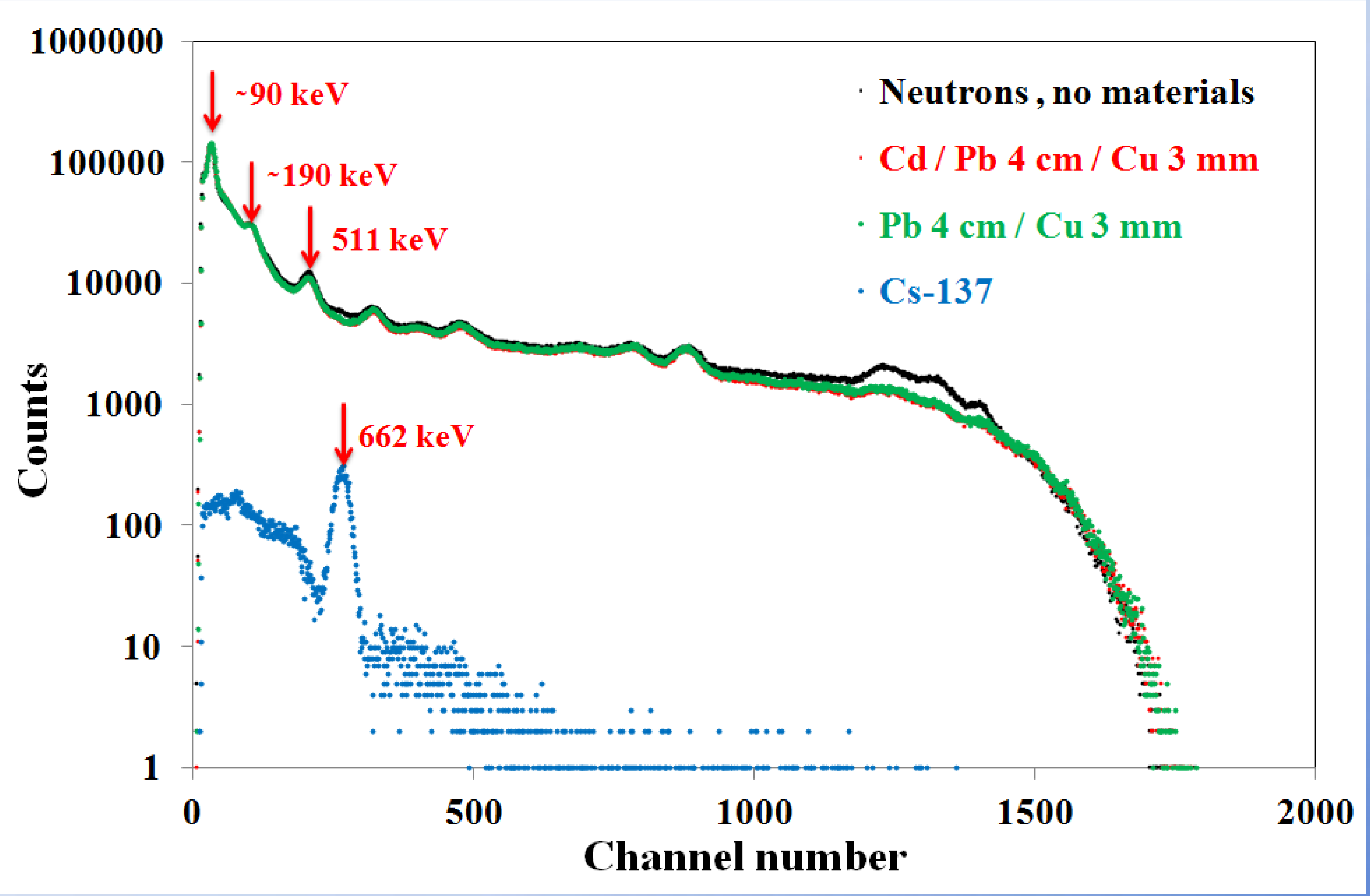
The γ-spectra measured with GAGG 3 mm sample irradiated by neutrons from Am-Be source.



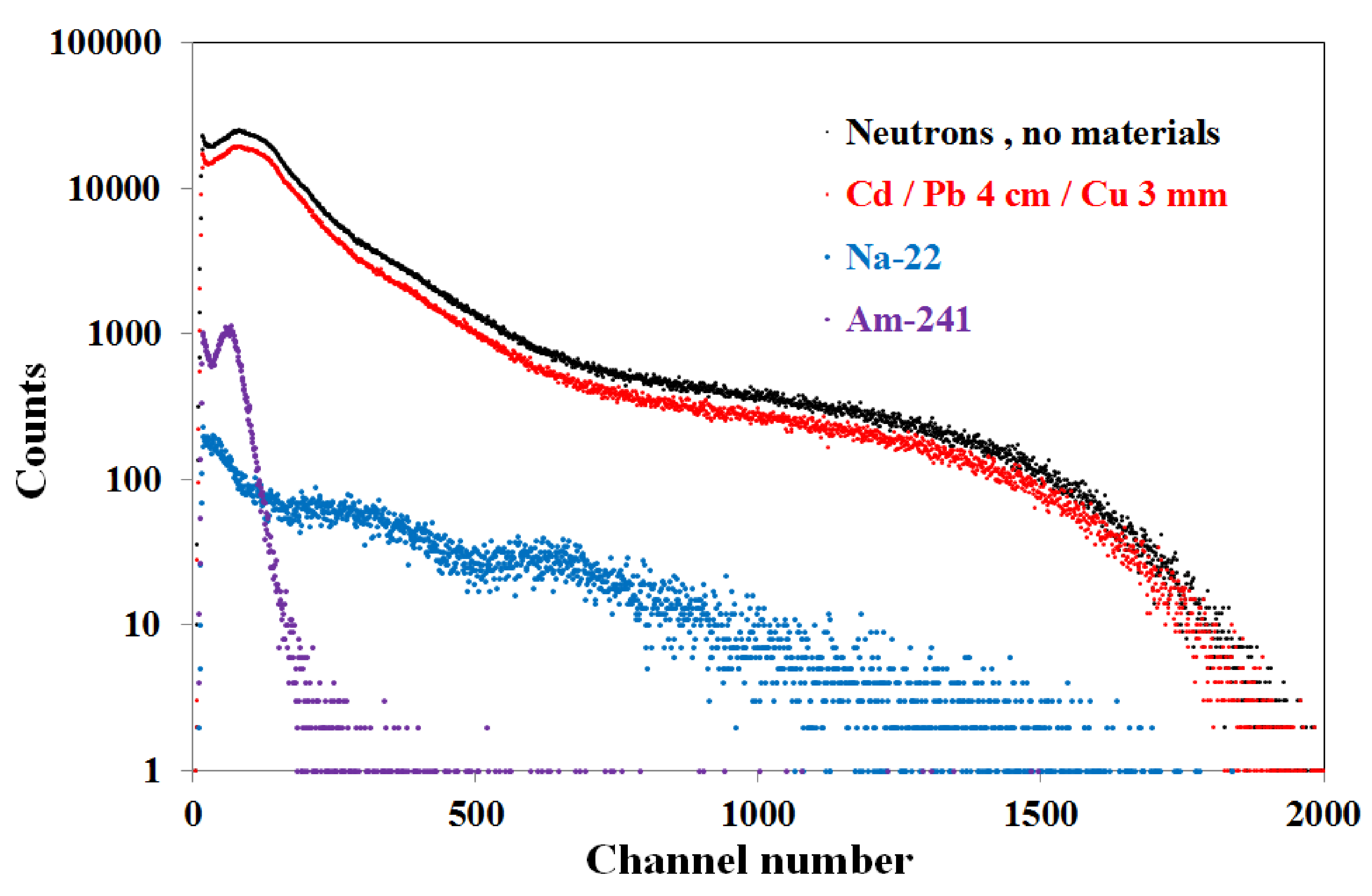
The γ-spectra measured with GAGG 7 mm sample irradiated by neutrons from Am-Be source.



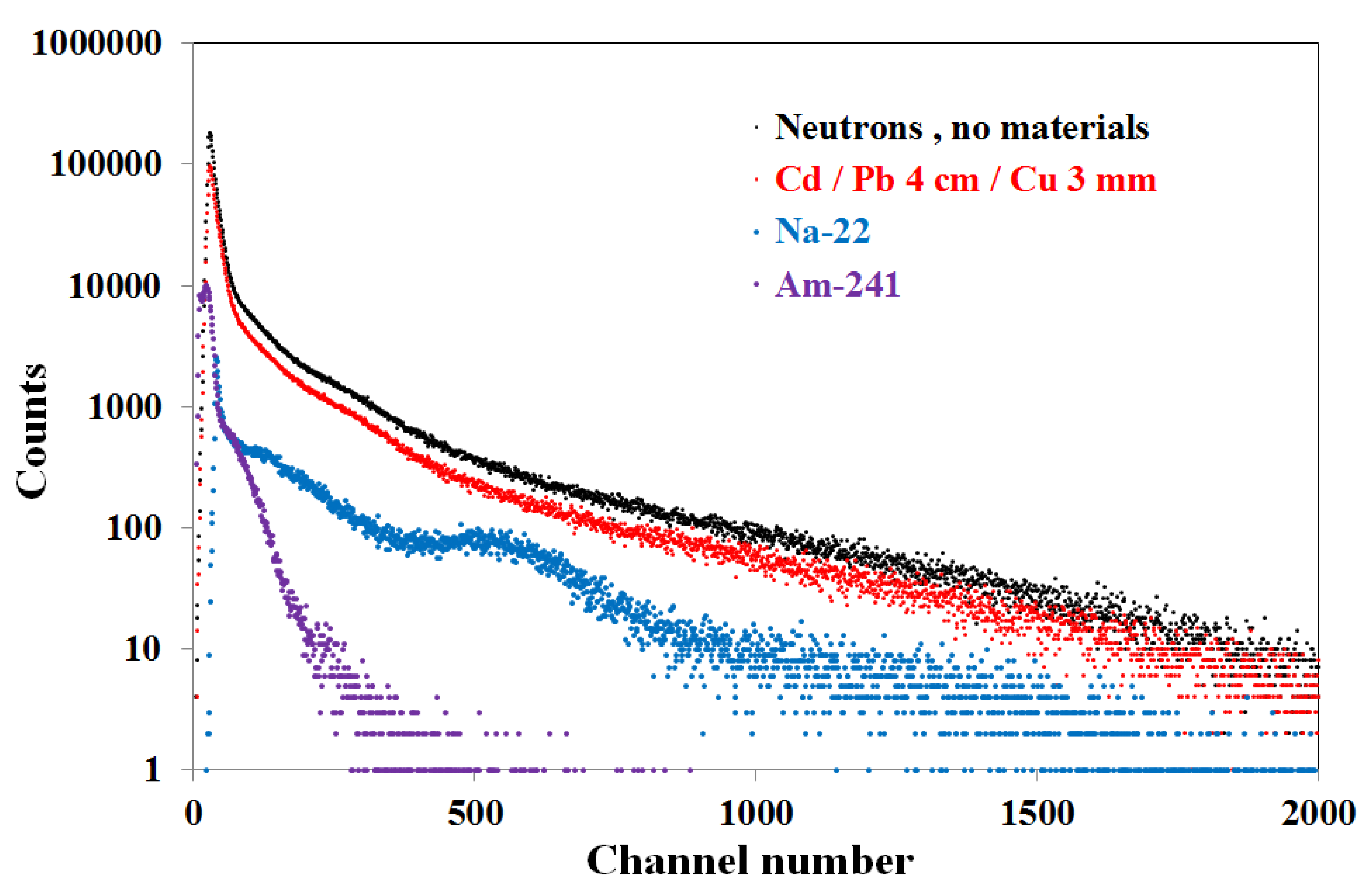
The γ-spectra measured with GAGG 25 mm sample irradiated by neutrons from Am-Be source.



The γ-spectra measured with GYAGG ceramics plate irradiated by neutrons from Am-Be source.



The γ-spectra measured with 4 cm DSB: Ce loaded with Gd sample irradiated by neutrons from Am-Be source.



Summary

- GAGG has a good potential to be applied for inhomogeneous detecting cells of electromagnetic calorimeters to operate in a harsh irradiation environment. Gamma-quanta, generated by neutrons in GAGG will appear under detector threshold at the registration of high energy particles while “shashlyk” or “spaghetti” type detectors will be used.
- The gamma-lines acquired with GAGG scintillation detector under neutron irradiation are located in the energy range up to 4 MeV with major γ-lines concentrated in the energy range below 0.6 MeV. Finally, the energy deposition of MIPs in 2 mm thick GAGG crystal plate amounts close to 1.5 MeV. Therefore, the overlapping with gamma-quanta generated by thermal and low energy neutrons will be negligible.
- Translucent GYAGG ceramics and glass ceramics DSB heavy loaded with Gd demonstrate the response on neutrons with energies above thermal. These materials can be an alternative solution to built large volume detector systems. But further optimization of the technology has to be done.