

Comparison of NaI(Tl) Detector Efficiency via Measurements and Monte Carlo Simulations and Modeling New Scintillation Detector System

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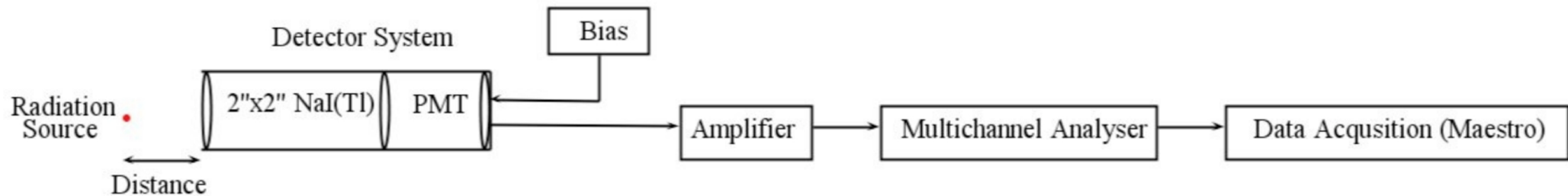
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Aim of the study

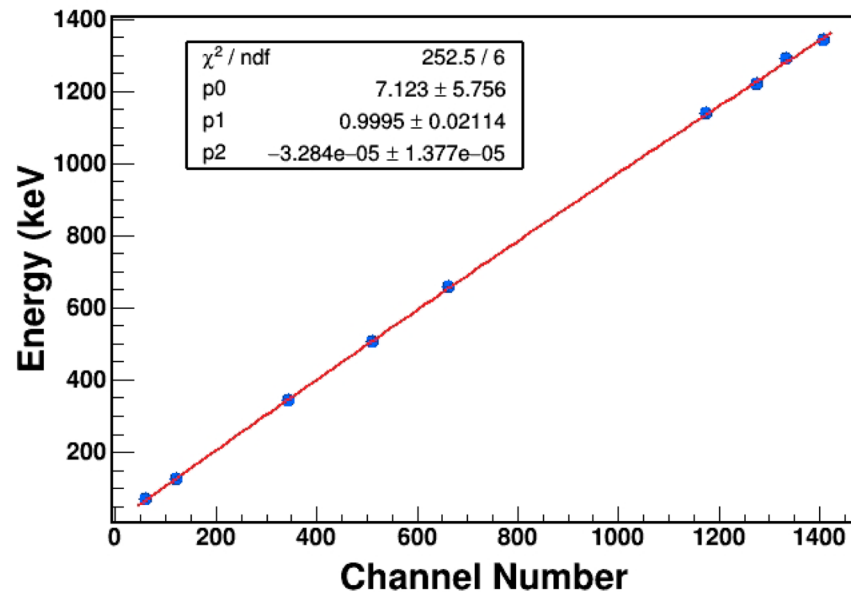
- ❖ Presentation of the energy calibration, energy resolution, and detector efficiency results for 2"x2" NaI(Tl) crystal obtained from experiment and simulation results for detector efficiency
- ❖ Modification of simulation into the novel scintillation detectors (LaBr₃, GAGG(Ce) and SrI)

Experimental Setup



- 2"x2" ORTECs ScintiPack Model 296 NaI detector
- ORTECs 572A Model amplifier, DigiBASE (Ortec) multi-channel analyzer (MCA) and the MAESTRO 32 multichannel analyzer emulation software
- ^{137}Cs , ^{60}Co and ^{152}Eu point sources and ^{241}Am , ^{22}Na cylindrical volume sources

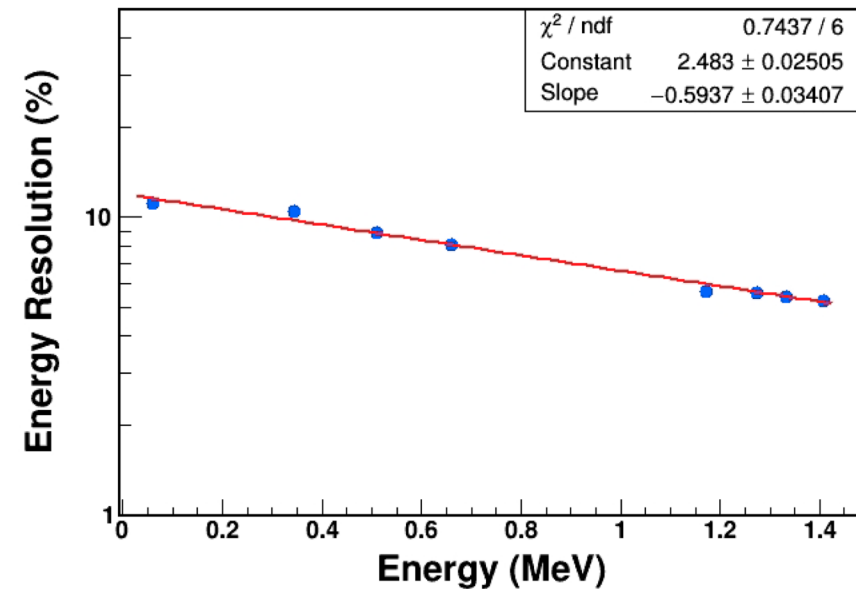
Experimental Results: Energy Calibration and Energy Resolution



Energy calibration of 2"x2" NaI(Tl) detector for 2 cm detector-to-source distance. The blue points correspond to experimental data and the red line expressed to second order polynomial fit:

$$E = p_0 + p_1C + p_2C^2$$

Counting time was 15 minutes.

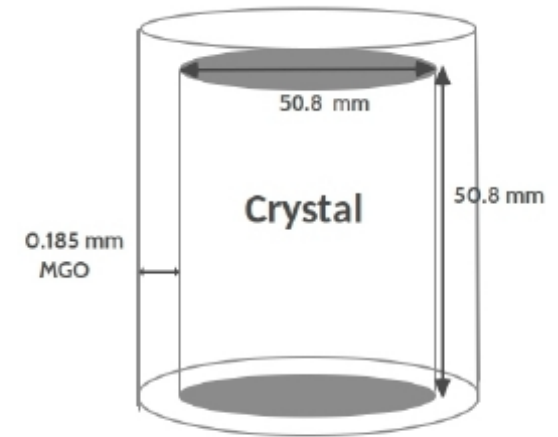


Energy resolution of NaI(Tl) detector system for 2 cm detector-to-source distance. The blue points correspond to experimental data and the red line expressed curves fit for energy resolution:

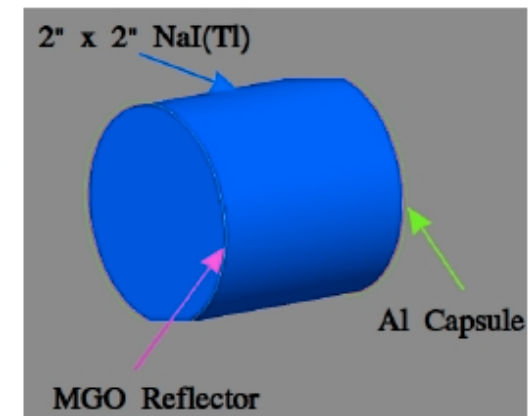
$$R = aE^b$$

GATE Simulation Code

- The cylindrical NaI(Tl) detector (NaI(Tl) crystal, MGO reflector, aluminium capsule), system identification, modeling of radioactive sources, specifying the physics list, sensitive detector concept, digitizer (signals measured by the detector after interacting with radiation) were modeled in GATE.
- GATE is a simulation toolkit that applies in nuclear medicine, such as PET, SPECT, CT, optical imaging, radiotherapy, the designing of medical imaging devices. It encapsulates the Geant4 libraries and consists of several hundred C++ classes.

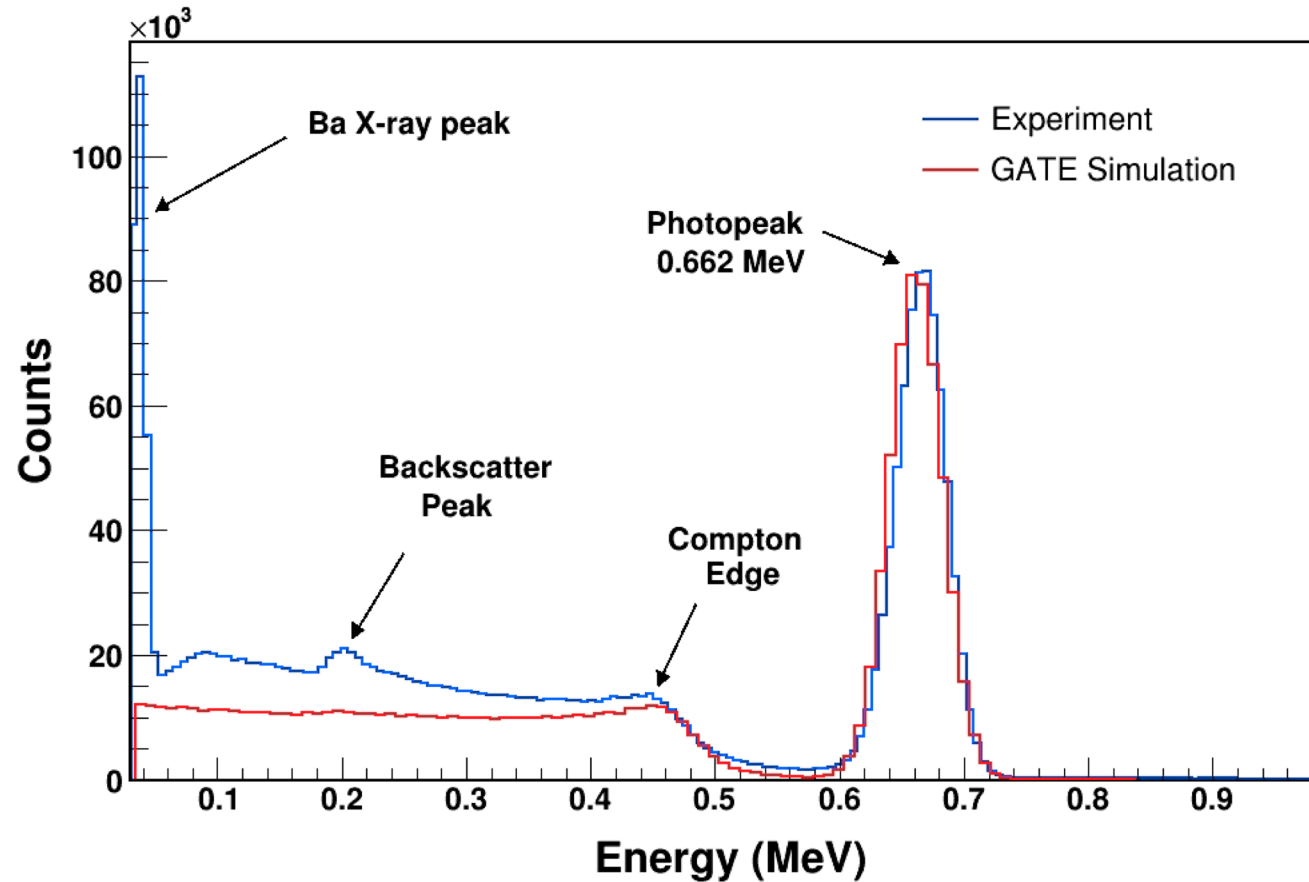


(a) NaI(Tl) detector dimension.



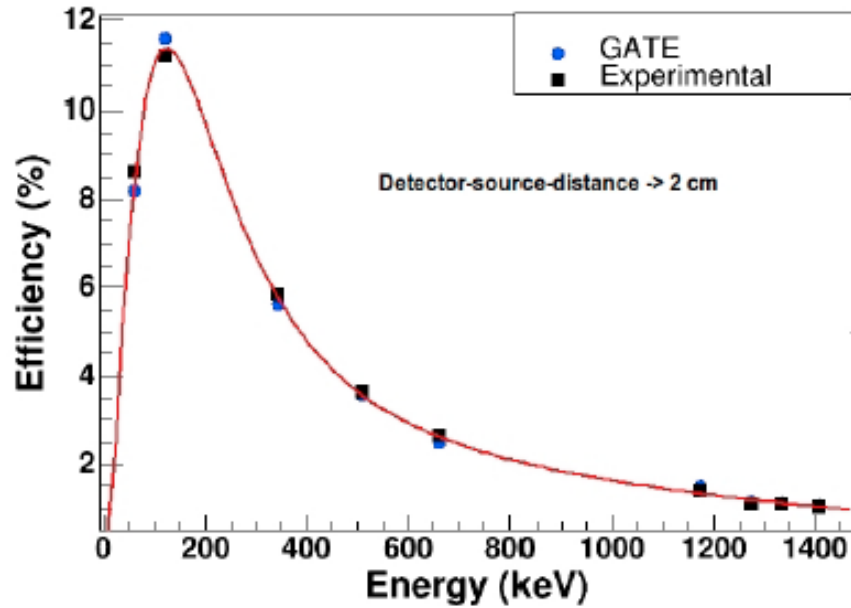
(b) Visualization in GATE simulation.

Results: Experiment and Simulation

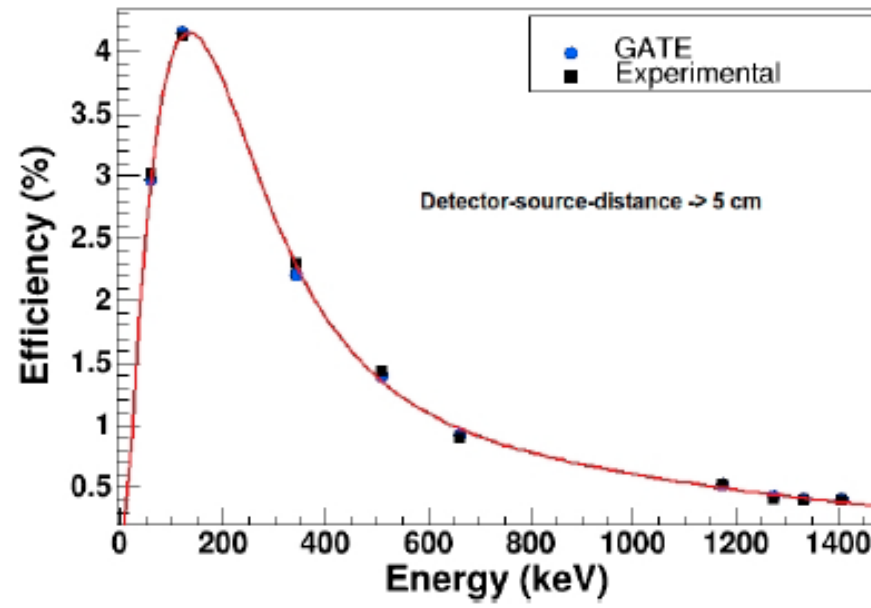


Comparison of experimental and simulated energy spectra obtained from NaI(Tl) detector at 662 keV for ^{137}Cs source

Results: Experiment and Simulation



(a) The detector-source-distance is 2 cm.



(b) The detector-source-distance is 5 cm.

Measured and simulated the full-energy peak efficiency percentage of the detector for locating at (a) 2 cm and (b) 5 cm.

$$\epsilon_{exp} = \frac{N}{t.P.A}$$

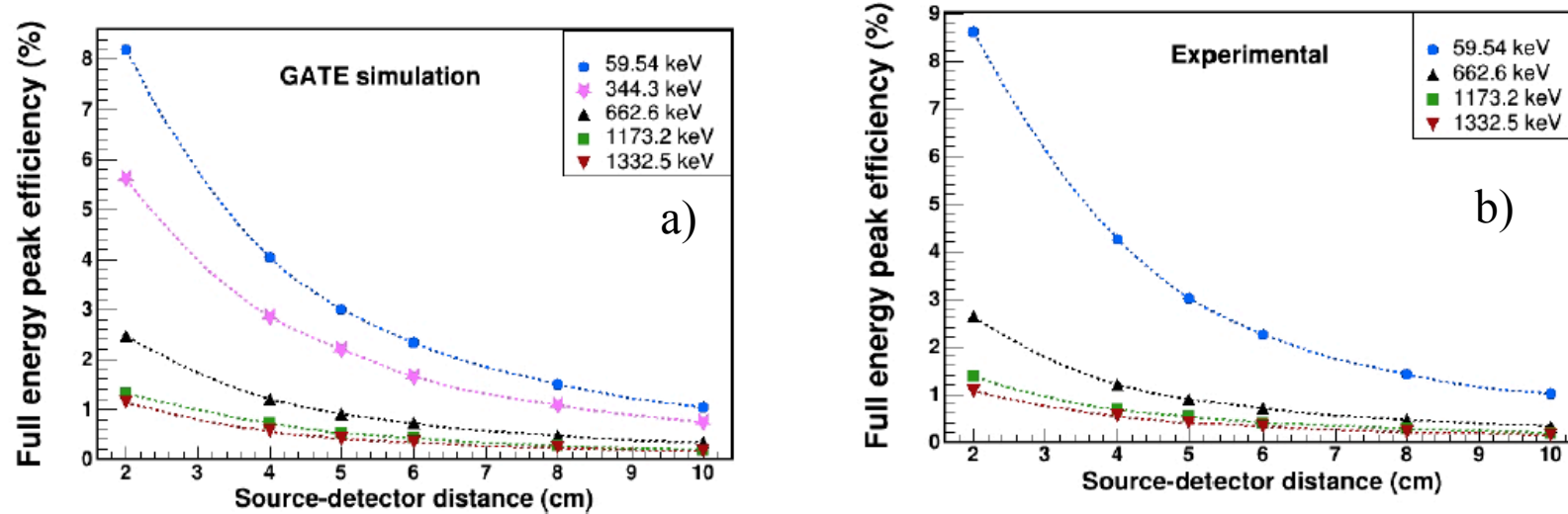
N , is the number of counts of the photopeak for the specifying energy,
 t , is the acquisition time,
 P , is the photon emission probability for each interested radionuclide,
 A is the activity of the radionuclide at the time of the measurement

Photon Energy (keV)	Distance (cm) ($\pm \Delta$) [†]	ϵ_{GATE} (%) [†]	ϵ_{exp} (%)	ϵ_{MCNP} (%)[6]	RD (%)
59.54	2	8.656	8.608	13.04	0.554
	4	4.226	4.259	-	0.791
	5	3.137	3.878	-	0.464
	6	2.404	2.263	-	6.229
	8	1.523	1.411	-	7.937
	10	1.071	1.012	-	5.828
121.8	2	11.577	11.175	4.79	3.597
	4	-	5.708	-	-
	5	4.153	4.117	-	0.874
	6	3.144	-	-	-
	8	1.969	-	-	-
	10	1.341	-	-	-
344.3	2	5.626	5.832	-	3.532
	4	2.849	-	-	-
	5	2.206	2.222	-	0.720
	6	1.656	-	-	-
	8	1.091	-	-	-
	10	0.758	-	-	-
511	2	3.556	3.617	-	1.686
	5	1.399	1.431	-	2.236
661.6	2	2.474	2.639	3.05	6.252
	4	1.214	1.201	-	1.082
	5	0.918	0.896	-	2.455
	6	0.719	0.699	-	2.861
	8	0.475	0.473	-	0.423
	10	0.338	0.328	-	3.059
1173.2	2	1.319	1.376	1.44	4.142
	4	0.726	0.669	-	8.520
	5	0.529	0.526	-	0.570
	6	0.433	0.405	-	6.914
	8	0.269	0.271	-	0.738
	10	0.192	0.181	-	6.077
1274.5	2	1.129	1.084	-	4.151
	5	0.433	0.406	-	6.650
1332.5	2	1.139	1.065	1.27	6.948
	4	0.560	0.533	-	5.066
	5	0.412	0.400	-	3.000
	6	0.334	0.316	-	5.696
	8	0.223	0.210	-	6.190
	10	0.154	0.142	-	8.451
1408	2	1.063	1.026	-	3.606
	4	0.531	-	-	-
	5	0.404	0.393	-	2.799
	6	0.317	-	-	-
	8	0.209	-	-	-
	10	0.148	-	-	-

Table of efficiency values of the cylindrical NaI(Tl) detector obtained by experiment and simulation at various source-detector distances for different photon energies (from 59 keV to 1408 keV) and the literature comparison.

$$RD = \frac{|(\epsilon_{GATE} - \epsilon_{exp})|}{\epsilon_{GATE}}$$

Results: Experiment and Simulation



The full-energy peak efficiency values versus source-to-detector distance (between 2-10 cm) obtained by (a) GATE simulation and (b) experimentally measurement in the photon energy range from 59.5 keV to 1332.5 keV.

Simulation Results: LaBr₃

Since the results obtained from the experimental and simulation for 2"x2" NaI detector were compatible with each other and with literature results, then the simulation model modified into the novel scintillation detectors:

Radionuclide	Photon Energy (keV)	Distance (cm)	ϵ_{GATE} (Present work)	$\epsilon_{\text{MCNP-X}}$ [6]	ϵ_{MC} [5]	ϵ_{exp} [5]
²⁴¹ Am	59.54	5	3.93	3.95	3.09	3.0
¹³³ Ba	302.85	5	2.29	2.34	2.01	2.0
	356.01	5	1.98	2.05	2.01	1.8
¹³⁷ Cs	661.66	5	1.34	1.45	1.31	1.3
⁶⁰ Co	1173.24	2	2.22	2.48	2.15	2.1
	1332.51	2	2.06	2.20	1.90	2.0

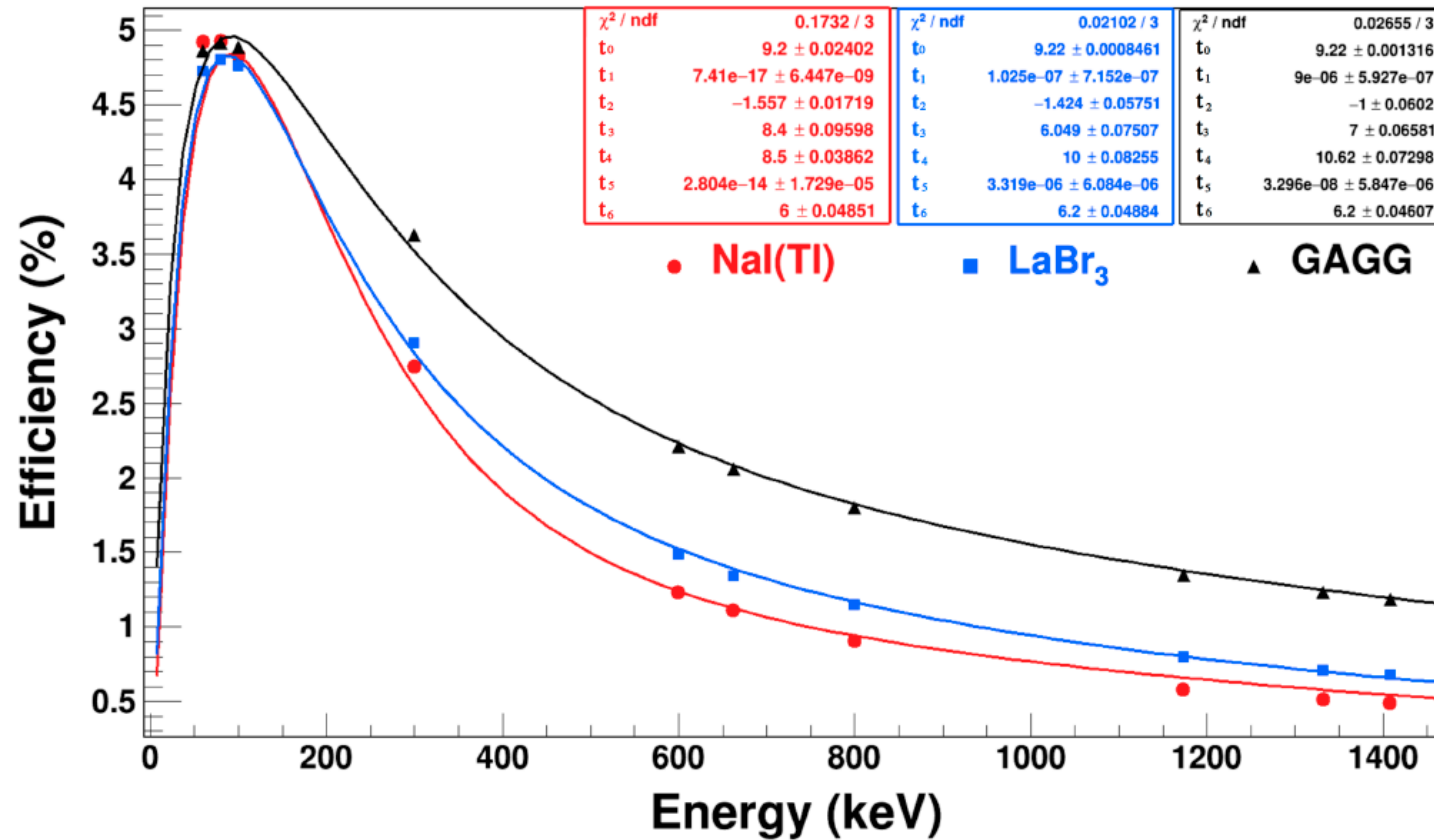
The comparison of the efficiency values for the cylindrical LaBr₃ detector (2"x2") with similar studies in the literature

Simulation Results

Photon Energy (keV)	ϵ_{GATE}			
	NaI(Tl)	LaBr ₃	SrI ₂	GAGG
60	4.9190	4.7230	5.0255	4.8611
80	4.9277	4.8011	5.0301	4.9154
100	4.8314	4.7613	4.9133	4.8904
300	2.7453	2.9013	3.0422	3.6252
600	1.2307	1.4827	1.4951	2.2081
662	1.1069	1.3406	1.3501	2.0559
800	0.9035	1.1498	1.1278	1.7981
1173	0.5782	0.8001	0.7888	1.3459
1332	0.5147	0.7087	0.6823	1.2290
1408	0.4854	0.6777	0.6663	1.1849

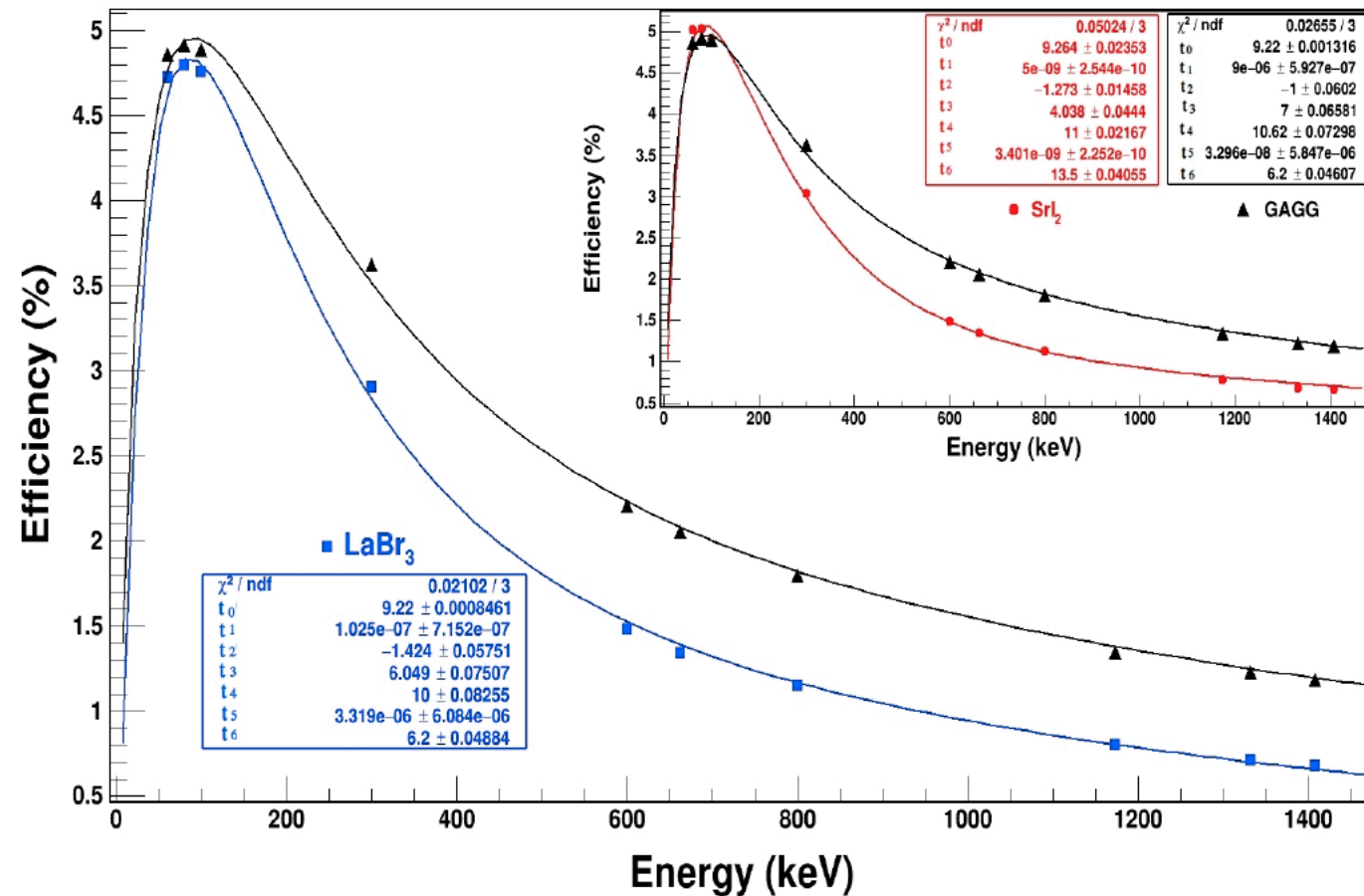
The percentage of peak efficiency values obtained by GATE simulation for the new generation detectors for 5 cm detector-source-distance. Isotropic point gamma-ray source with 4000 Bq activity is defined in the simulation in this part.

Simulation Results



The percentage of the full-energy peak efficiency curve for NaI(Tl) and new scintillation detection systems with their fitting parameters

Simulation Results



Simulated the full-energy peak efficiency percentage for newly scintillation detector systems and comparison with their fitting parameters shown in the figures.

Conclusions

- ❖ Complete calibrations (energy, energy resolution and efficiency calibrations) of 2"x2" NaI(Tl) scintillation detector were represented.
- ❖ In terms of efficiency calibration, Geant4 based GATE simulation code is developed to validate real gamma-ray spectra and efficiency measurement.
- ❖ Simulation results were compared with the experimental results for 2"x2" NaI detector system. Experimental efficiencies and fitting parameters are in good agreement with calculated values obtained from the simulation.
- ❖ It was seen that the efficiencies decrease exponentially with the increasing distance from the detector face in agreeing with the literature.

- ❖ Developed simulation code was modified into new scintillation systems. The calculated efficiency value in GATE for LaBr_3 is consistent with the literature. Different new scintillation detector systems are also modeled in the simulation, and the parameters used in the analytical equation of the efficiency curve obtained.
- ❖ GAGG is a new detector system that gives promising results in energy and time resolution studies in the literature. There is not any work related to the gamma efficiency of the GAGG and comparing novel scintillators.
- ❖ Among the detectors, the highest gamma efficiency was found for GAGG. That will provide effective outcomes laboratory measurements and areas where scintillation detector systems are commonly used, such as medical imaging.

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